WATER SUPPLIES IN BENGAL

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BY

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PREFACE.

Water, though not strictly speaking a food, is absolutely necessary for the maintenance of life. A man may live for many weeks without food, but in the absence of water, life is only a matter of days. Water is concerned with the osmotic equilibrium of the tissues, serves as a solvent and diluent of the solid foods so that they may be properly digested and assimilated, flushes the waste products out of the system, and is of especial value in getting rid of the increased heat from the body by the evaporation of sweat. A large amount of water is lost from the body in the urine, sweat, breath, fæces and other secretions. To make good this loss, an adult person should drink about 3 pints of water (more, of course, when active exercise is taken or in hot weather) in 24 hours, besides the amount of water taken in as component parts of solid foods and that obtained from their oxidation. A cup of tea or a glass of milk can replace an equivalent amount of water. The exigencies of modern civilization, however, demand a far larger supply. Water is indispensable for the cooking of food and for the cleansing of the person and of the

in a year. Intensive farming, however, necessitates adequate watering and manuring, proper methods of cultivation and the substitution of improved strains of seeds for the inferior low-yielding varieties.

This thesis is concerned with four principal considerations: firstly, the water resources of Bengal and their economic development; secondly, the characteristics of water from diverse sources; thirdly, the diseases spread through the medium of water; and fourthly, the methods usually employed for the purification of water. The writer has supplied references whenever he has availed himself of the work of others; his chief obligations have, however, been to—

Imperial Gazetteer of India, Bengal.

Bengal District Gazetteers.

Geography of Bengal—W. H. Arden Wood.

The Examination of Water and Water Supplies—J. C. Thresh.

Hygiene and Public Health—Kenwood and Kerr.

Preventive Medicine and Hygiene—M. J. Rosenau.

Annual Reports of the Society of Chemical Industry on the Progress of Applied Chemistry.

N. K. Ray.

CONTENTS

WATER SUPPLIES IN BENGAL

CHAPTER I

Sources of Water

The original source of natural water is the atmospheric water vapour condensed in the form of rain and snow. The snowfields and glaciers of the Himalayas feed a large number of the rivers in India. We mostly depend, either directly or indirectly, upon rain for our water supplies. After having fallen, a certain portion of the rain water is lost by evaporation ; another portion sinks into the ground forming and renewing the underground sources of water which are available to man through "springs" and "wells ;" the remainder, which is the greatest portion of the rain water, runs off the surface and accumulates, in mountainous countries, in natural depressions forming "mountain lakes," furnishes ordinary surface water as " bils " (that is, natural swamps or marshes) and artificially-made " tanks," and swells the " rivers " and " water

courses." The extent to which each process takes place is regulated by a variety of circumstances, such as the amount of the rainfall, the temperature of the air, the slope of the surface and the porosity of the soil. The sources of water may therefore be classified as rain or snow water, surface water including lakes, bils, tanks, rivers and watercourses, and underground water including springs and wells. The water resources of Bengal will now be considered in more detail.

be noted that the Indian monsoons[1] are periodical winds that blow over the Indian Ocean and adjacent lands—a north-east monsoon blowing from October to March and a south-west monsoon blowing from April to September. Over most parts of India, the north-east monsoon is the regular north-east trade wind of the northern hemisphere and is quite dry. In north-west India it is, however, interrupted from time to time during the four months December to March by the arrival of barometric depressions coming from the Mediterranean across Syria and Persia. These storms bring winter rain to north-west India and more or less snow on the mountain zone to the north and west, but practically die out before they can reach Bengal. The reversal of the north-east monsoon (that is, its change into a south-west monsoon) is the result of the sun's heat upon the lands of India. By April, the air over these lands becomes hotter and less dense than that over the Indian Ocean, and consequently air passes from the region of higher pressure over this ocean across the Arabian sea and the Bay of

1 "Climate," W. G. Kendrew.
"The Weather"—C. E. P. Brooks.
Imperial Gazetteer of India, Bengal.

Bengal to the region of lower pressure in India, and being deflected by the earth's rotation to the right, becomes the south-west monsoon. These winds do not immediately bring general rains, because at first they are not sufficiently laden with moisture. The April and May showers of rain and hail in Bengal are largely due to local storms known as nor'-westers. The low pressure system over India, however, deepens with the increasing heat of summer, and early in June, the pressure over India becomes so low and the sub-tropical anti-cyclone of the South Indian Ocean becomes so much intensified that the south-westerly winds, which now reach India after travelling for 4,000 miles over the sea, carry large quantities of air heavily charged with water vapour. It is this water vapour which provides the rainfall of the south-west monsoon. It has been previously mentioned that the condensation of the water vapour takes place when a current of moist air is chilled by expansion as it ascends. The ascensional movement of air is due to several processes which probably act in combination to produce the heavy rain in most regions; the chief of these processes may be stated as follows:—

(1) The high temperature over the land causes the air to expand; it therefore becomes

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termed "the monsoon." In this sense the monsoon normally begins in Ceylon in the last week of May, in Bombay about June 5, in Calcutta a week later, and in the north-west not until nearly the end of June. The monsoon current is by no means steady, so that periods of general rain alternate with intervals of dry weather; the 'breaks' are as a rule terminated by the advance of cyclonic storms from the Bay of Bengal into the interior. The monsoon continues till the middle of September over all parts of India and then retreats, the north-west being the first part of the country to lose it. It ceases in Bengal towards the end of October and in the south-east of the Deccan at the end of December.

The monsoon rainfall in India is influenced by several factors:[1]—

(*i*) When there is a large accumulation of snowfall at the end of May in the mountain zone bordering India on the north and west, dry northerly and north-easterly winds are set up and the rains tend to be diminished and delayed, especially in north-west India.

[1] "The Causes of the Monsoons"—G. T. Walker (The Oxford Survey of the British Empire; Asia, pp. 71-72).

Normal Rainfall (in inches) in the Districts of Bengal.[1]

Districts.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total for year.
Burdwan Division													
Bankura	·40	1·02	1 21	1·34	4·38	9 89	11·47	11·31	8·11	3·47	·66	08	53 34
Burdwan	·27	1·09	1 63	1·65	4·88	10 81	11·00	11·62	8·07	4·19	·72	·10	55·93
Birbhum	·41	·73	·97	1·16	4·24	10 65	12 43	11·96	9·35	3·54	·49	·07	56·02
Hoogly	·37	1 16	1·45	2·17	5·58	9·90	11·84	11·41	8·54	3·91	·61	·21	57·15
Midnapur	·33	1·10	1 67	1·72	5·29	11 83	11·54	11·42	8·71	5·31	1 ·07	·13	60·12
Howrah	·42	1 29	1·71	2·07	5·52	11·73	12·59	12·13	8·43	4·15	·64	·19	60·87

[1] Reports of the Director of Agriculture, Bengal, published in Supplement to the Calcutta Gazette of the 11th March, 1926.

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Burdwan	·27	1·09	1·03	1·65	4·88	10·81	11·00	11·52	8·07	4·10	·72	·10	56·93
Birbhum	·41	·73	·97	1·16	4·24	10·65	12·43	11·96	9·35	3·54	·49	·07	56·02
Hoogly	·37	1·16	1·45	2·17	5·58	9·90	11·84	11·41	8·54	3·91	·61	·21	57·15
Midnapur	·33	1·10	1·07	1·72	5·20	11·88	11·64	11·42	8·71	5·31	1·07	·13	60·12
Howrah	·42	1·29	1·71	2·07	5·52	11·73	12·50	12·13	8·43	4·15	·64	·19	60·87

[1] Reports of the Director of Agriculture, Bengal, published in Supplement to the Calcutta Gazette of the 11th March, 1926.

(*ii*) The ascensional movement of air near the equator must greatly diminish if the winds from the South Indian Ocean are to flow into India ; and if the equatorial rainfall in April and May is heavier than usual, it implies that the ascensional movement is abnormally strong, and hence that conditions are unfavourable.

(*iii*) High pressure in the Indian Ocean in May tends to produce high pressure and anti-cyclonic conditions in India.

(*iv*) High pressure in the Argentine Republic and Chile in March, April and May is usually associated with low pressure in the Indian Ocean, and each of these has been found to be favourable for the Indian monsoon.

(*v*) High pressure in India in the previous year is usually followed by abundant rain.

(*vi*) The presence of icebergs in unusually large numbers in the southern portion of the Indian Ocean is favourable to Indian rainfall.

The following tables show the normal rainfall of Bengal Districts :—

Normal Rainfall (in inches) in the Districts of Bengal.[1]

Districts.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total for year.
Burdwan Division													
Bankura	·40	1·02	1 21	1 34	4·38	9 89	11·47	11·31	8·11	3·47	·66	08	58 34
Burdwan	·27	1·09	1 63	1·05	4·88	10 81	11·00	11·52	8·07	4·19	·72	·10	55·93
Birbhum	·41	·73	·97	1·18	4·21	10 65	12·43	11·96	9·85	3·51	·49	·07	50·02
Hoogly	·37	1 16	1·15	2·17	5·58	9·90	11·84	11·41	8·54	3·91	·61	·21	57·15
Midnapur	·33	1·10	1 67	1 72	5·29	11 83	11·64	11·42	8·71	5·31	1 ·07	·13	60·12
Howrah	·42	1 29	1·71	2·07	5·52	11·73	12·59	12·13	8·43	4·15	·64	·19	60·87

[1] Reports of the Director of Agriculture, Bengal, published in Supplement to the Calcutta Gazette of the 11th March, 1926.

Normal Rainfall (in inches) in the Districts of Bengal (contd.).

Districts.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total for year.
Presidency Division													
Nadia	·33	·98	1·63	2·75	6·40	9·95	9·97	10·19	7·75	3·91	·70	·13	54·69
Murshidabad	·37	·76	1·02	1·55	5·29	10·52	10·83	11·16	9 25	3·93	·59	·10	55·37
Calcutta (Alipur Observatory)[1]	·41	1·15	1·25	1·75	5 71	11·43	12·89	12 16	10·35	3·91	·56	·21	61·81
Jessore	·39	1·21	2·00	3·53	7·39	11·90	11·08	10·74	8·58	4·53	·73	·18	62·31
24-Parganas	·42	1·16	1·60	2·03	5·58	11·57	13·06	12·63	9·70	4·91	·82	·21	63·69
Khulna	·45	1·23	2·07	3·72	7·43	13·28	14 77	13 12	10·05	5·46	·88	·15	72·61

[1] Memoirs of the Indian Meteorological Department, Vol. XXII, Part I.

Normal Rainfall (in inches) in the Districts of Bengal (contd.).

Districts.	January.	February.	March	April.	May.	June.	July.	August.	September.	October.	November	December.	Total for year.
Rajshahi Division													
Malda	·41	·79	·73	1·21	4·62	10·68	12·10	11·58	9·61	3·84	·42	·07	56·06
Rajshahi	·41	·65	·95	1·67	5·89	11·30	11·62	10·75	9·90	4·24	50	·07	58·04
Pabna	·19	·79	1·35	2·88	7·02	11·33	10·57	11·23	8·82	4·87	·49	·13	59·67
Bogra	·33	·72	1·00	2·27	7·49	11·92	12·07	11·54	10·42	4·73	·49	·07	63·05
Dinajpur	·26	·68	·82	1·94	6·71	14·61	16·21	14·62	12·08	4·16	·22	·06	72·37
Rangpur	·25	·64	1·16	3·22	10·60	17·41	15·25	13·48	13·33	5·52	·30	·07	81·23
Darjeeling	·56	1·00	1·71	3·97	9·16	21·39	31·45	25·85	18·28	4·52	·62	·27	121·78
Jalpaiguri	·43	·88	1·87	5·55	14·09	28·41	34·50	27·75	21·92	6·07	·48	·19	142·09

Normal Rainfall (in inches) in the Districts of Bengal (contd.).

Districts.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total for year.
Dacca Division													
Faridpur	·29	1·12	2·29	5·10	8·95	14·52	12·85	12·98	8·59	5·58	·73	·22	73 22
Dacca	·31	1·09	2·64	5·85	9·27	14·02	13·27	12·78	9·16	4·90	·78	·18	74·25
Mymensingh	·31	·81	1·72	4·55	11·15	17·83	16·70	17·09	12·49	5·68	·64	·10	89·07
Bakarganj	·37	1·12	2·04	4 53	9·25	18·38	18·41	16·64	11·97	6·79	1·31	·29	91·13
Chittagong Division													
Tipperah	·37	1·08	2·88	6·47	10 71	18·01	13·75	14 90	10 32	5·26	·96	20	84·91
Chittagong Hill Tracts	·14	·75	2·37	5·81	7·72	19·35	22 18	19·77	13 25	6·22	1·83	30	99·69
Noakhali	·24	·99	2·60	6 15	10·48	21·28	23·55	23·48	15·34	8·18	1 56	·37	114·22
Chittagong	·21	·68	2 18	5·14	10·38	23·11	26·42	23·18	13·21	7·01	2·37	·56	114 45

The foregoing tables show that Bengal is favoured with an abundant rainfall, the bulk of which (about 75 per cent. of the total) is received during the four months June to September. Apart from its irregular distribution throughout the year, the rainfall is also characterised by its unequal distribution over the country. The south-west monsoon is diverted northwards by the mountain range on the western side of Burma, causing increasing rainfall in Eastern Bengal. As it flows northwards, it is checked by the Himalayan range which causes it to rise high enough to condense its moisture into rain ; in fact, the regions of heaviest rainfall in Bengal are the hill district of Darjeeling and places bordering it. Excluding these places, the areas of greatest precipitation are the districts along the coast which are first struck by the monsoon current.

Rain as a Source of Water Supply.

Rain water is seldom used directly as a source of public water supply except where no other source is available, because of difficulties in collection and storage. From whatever source our water supply may be obtained, it is, however, dependent for replenishment upon the rainfall.

Every year during the months preceding the breaking of the monsoon, there is a scarcity of good drinking water in rural areas of Bengal. In the villages, most of the wells fail, the tanks either dry up or contain a small amount of dirty water, and the smaller rivers and khals are mere threads of water or become empty ; even the perennial rivers shrink much in breadth and the height of water falls considerably. As a result there is a considerable difficulty to get good drinking water. But with the recurrence of the rainy season, all is changed ; the tanks are filled up, the sub-soil water level is raised so that the volume of water in the wells and springs is increased, and khals and rivers rush down brimful and in many parts overflow and inundate the country for miles along their banks. The inundation sometimes causes widespread misery and at other times is hailed with joy according to its depth and duration and the fertilising qualities of its silt. Not only our drink, but our food also is at the mercy of the rainfall, as crops can only grow if the rainfall is adequate in the right season for them, or if artificial irrigation can be supplied. Rice is the most important crop of Bengal. This province is perhaps the foremost rice-producing region of the world. The association of monsoonal rains and

river floods with the full heat of summer furnishes ideal conditions for rice. Next to rice the most important crop is jute, and Bengal, especially Northern and Eastern Bengal, is admirably adapted for its production, the area under jute in the province representing some 85 per cent. of the total area under jute in British India. Jute is sown in March to May and harvested in August and September, and the area under this crop is increased considerably and the out-turn keeps up the normal level when there is a seasonal and adequate rainfall throughout.

One of the most remarkable features of the rainfall of Bengal is the occasional occurrence of excessive local precipitation. The natural effect of a heavy downpour is to cause the rivers, particularly those flowing from the hills and those lined with protective embankments, to swell very rapidly, and when their mouths are insufficient to discharge the excess of water, the banks are overflowed and large areas of the country remain submerged for weeks. The most destructive floods occur in the middle and end of the monsoon (for the heavy rain in the beginning are largely absorbed by the empty channels and reservoirs), particularly when the rivers rise very high owing to excessive rainfall, and being met by high tides

are unable to discharge their water quickly. In consequence, there is direct loss of life due to drowning and indirect mortality on account of famine caused by the destruction of rice crops and disease.

CHAPTER III

LAKES AND BILS

Lakes are accumulations of water in the natural depressions of the earth's surface. Some of the lakes are situated in the basins of rivers; others, the mountain lakes, are formed when a stream running down a hillside, meets with a hollow in the slopes, and before it can run away further it must fill this hollow with water. There are only a few notable lakes in Bengal. In the district of Chittagong Hill Tracts,[1] there are two lakes—the Bogakine situated on the Sangu river and the Rhainkhyongkine situated on the water-shed of that river. The Salt Water Lake lying a few miles east of the city of Calcutta, is a tract of low country regularly submerged by the tide and the natural process of silting is constantly diminishing the area; a portion of the Lake at Dhapa is being gradually reclaimed by the deposit of the street refuse which is conveyed daily from Calcutta by the Municipal railway. In

[1] Chittagong Hill Tracts District Gazetteer.

Sikkim there are two lakes lying at altitudes of over 12,000 feet; these are the Changu near the Nathu La pass and the Bidangcho near the Jelep La, the latter being "one of the best instances of a glacial lake in a valley whence a glacier has recently retired." [1]

The name "Bil" is given to any permanent piece of shallow water in swampy, low-lying grounds whether connected with a river or not. In most cases the bils are formed in the following manner:—The rivers by silt deposits for centuries raise their beds and their banks. When the rivers overflow, the silt is deposited all over the flooded country; but the deposit is thickest near the rivers where the flood water is the muddiest, the water gradually clearing itself as it moves inland. Hence the tracts between two deltaic distributaries lie lowest and form a kind of trough and collect the surface water and form bils. In some cases a string of bils is found along a line of drainage, which suggests that they represent the remains of some great river which centuries ago deserted its channel and sought its course elsewhere.[2] Sometimes the bils are connected

[1] "Tours in Darjeeling and Sikkim," W. J. Buchanan.

[2] Rajshahi *District Gazetteer.*

with rivers by khals ; in many cases the bils have lost their connection with the river owing to the silting up of khals or alterations in the course of the rivers.

The bils are met with all over Bengal, but they are especially numerous in the south of Faridpur District and in the north-west of Bakarganj. Chalan Bil (about 15 miles long and 9 miles broad) lying partly in Rajshahi and partly in Pabna Districts, is the largest in Bengal and of widest repute. This and most other bils are, however, gradually silting up and are being converted into fertile paddy lands. It may be noted that the bils are the natural homes of *boro* paddy (which is sown in November to January and harvested in April and May) because no cultivation is possible here except in the dry weather owing to the presence of too great a depth of water and also because the water required by the plants is not available except in the bils.

Lakes and Bils as Sources of Water Supply.

As has been mentioned previously, there are only a few lakes in the province. The water of the Bogakine Lake in Chittagong Hill Tracts is quite fit for drinking purposes. " A curious trait of this piece of water is that no fish can live in

it, nor is there any weed growth."[1] The Rhainkhyongkine is a mountain lake of great beauty and well stocked with fish.

The bils are abundant in Bengal and are occasionally resorted to for drinking water supplies when there is no other source of water in the vicinity. The chief use of bils is to serve the purpose of water highways, especially during the rains, and sometimes to steep jute and wash the fibre.

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[1] Chittagong Hill Tracts District Gazetteer.

CHAPTER IV

TANKS

Tanks are widely scattered in Bengal and all varieties of tanks—from small pits to large tanks called dighis, sagars, etc.—are found in the province. Until comparatively recent times tanks appear to have been the favourite artificial sources of water in most places in Bengal : only in certain areas, notably in the Madhupur Jungle Tract (which runs through part of Mymensingh and part of Dacca Districts) and in parts of the Rajshahi and Burdwan Divisions, tanks are not suitable because on account of the porous nature of the subsoil it becomes too expensive a matter to excavate them to a depth sufficient for providing a perennial supply of water.

Tanks are excavated for supplying earth in the preparation of house-sites in the low-lying country as well as for providing the homestead with a water supply. In some places, notably in Noakhali, in the islands in the Meghna estuary such as Hatia, Sandwip, etc., in the greater portion of Bakarganj District and elsewhere, the water from rivers and

khals is brackish practically all the year round; consequently, tanks are absolutely necessary for catching and retaining the rain water. In some cases, however, the landlords prohibit the excavation of new tanks or insist on the payment of exorbitant *salami*; as a result, the ryots cannot afford to provide themselves with the water supply. Large tanks owe their origin to the piety or desire for fame of some raja or land owner; they are also excavated in commemoration of some person. The Mahipal Dighi lying about 18 miles southwest of Dinajpur is supposed to have been excavated by Raja Mahipal who, according to an inscription found at Nalanda, reigned in 856 A.D.; the sheet of water extends 3,800 feet from north to south and 1,100 feet from east to west.[1] In Comilla the big tank known as Dharma Sagar is called after Raja Dharma Manikya.[2] There is a large tank at Madhabpassa in Bakarganj District which is called Durga Sagar after Raja Jay Narayan's mother.[3]

Tanks are usually filled by the annual rains; sometimes a large volume of water is derived from underground infiltration also. In some parts

[1] Dinajpur District Gazetteer.
[2] Tipperah District Gazetteer.
[3] Bakarganj District Gazetteer.

large size and the owners get the benefit of a good supply of fishes which may be used by themselves and also sold to the public at a profit. The money spent on excavation and re-excavation can thus be recovered in the course of a few years.

Tanks as Sources of Water Supply.

People depend to a large extent upon tanks for their water supply. In fact, villages which are not actually situated on the banks of a river or khal or on the edge of a swamp, obtain their supplies either from tanks or from wells. Tanks may be excellent sources of water supplies provided they are well-kept and reserved for the purpose of supplying drinking water alone. Unfortunately, no steps are usually taken to protect the water from contamination, and the tanks are, as a rule, extremely dirty and stinking as they contain a large amount of accumulating organic débris in a highly putrid condition. Usually, the tanks collect the surface drainage ; the rain water, as it passes along the streets, carries with it partly in solution and partly in suspension large quantities of animal and vegetable matters—human faeces, cow-dung, urine, decayed vegetable substances, etc., to be finally deposited in the tanks. The

tanks are used indiscriminately for all domestic purposes; people bathe in the tank, spit and wash their mouth and teeth whilst bathing, wash their clothes and kitchen utensils in the tank water and throw all the shards and remains of meals and other miscellaneous unwanted trifles into the tank. There are floating and submerged aquatic plants in the tanks. Barha (large) pana (*Pistia stratiotes*) and Khudi-pana or Duck-weed (*Lemna trisulca*) are the predominant aquatic plants floating on the surface of most tanks and affording breeding places for mosquitoes. In some cases the tanks are choked with water hyacinth and other weeds, and overshadowed with trees or surrounded with jungles. The water is thus polluted by the decay of weeds or leaves thrown or blown into them. Even when the tank and its sides are kept clean and free from weeds and grass, the growth and decay of microscopic plants (*e.g.*, algae) often produce offensive smell. Open air defaecation along the banks is a common practice, and the faeces may be washed into the tank, or the desiccated faecal particles may be blown into them. After defaecation, the people go to the tanks to wash themselves; they also wash their clothes soiled with urine and stool in the tank water. Privies are generally made in close

proximity to the tanks, often a few feet away from the water; as a result, excrementitious liquids may soak through the few feet of porous soil into the water. The faecal pollution of the water becomes particularly dangerous when the faeces contain disease-germs such as those of cholera, typhoid fever, etc. For instance, even traces of excreta of a cholera patient on a soiled "dhoti" or "sari" may suffice to infect the water of the tank in which it is washed, and may give rise to many cases of cholera. When a tank is actually contaminated with faecal matter containing specific germs of diseases, complete reservation for a period of about a fortnight will render the infected tank safe for use on account of the destruction of the disease-germs by exposure to direct sunlight and heat. This auto-purification takes place most quickly in the dry weather when the sky is clear and the sun is bright and the tanks are not over-shadowed with trees. When the sky is cloudy and the days are wet and the tanks are surrounded with jungles they, if once infected, are likely to remain so for longer periods.

CHAPTER V

Rivers and Water Courses

Bengal is well described as the land of rivers. The province is traversed by the lower courses of the three great rivers—the Ganges, the Brahmaputra and the Meghna—which unite their waters before debouching into the Bay of Bengal. The great rivers, as they flow through the country, receive many tributaries, and throw off numerous distributaries ; these again have their affluents and offshoots ; the offshoots in turn ramify into smaller rivers which may re-enter the parent channel, join other rivers or make their way into the sea. The smaller rivers are also connected with each other by minor watercourses, commonly called " khals." The country is thus covered by a network of rivers and khals. It is far beyond the scope of this treatise to enumerate and describe the courses of all the rivers and khals of the province. A brief account of the principal rivers will only be given.

The Ganges.—It rises in the Tehri State (in 30° 55′ N and .9°7′ E) where it issues from an ice-cave known as Gai-mukh or Cow's Mouth at the

foot of a Himalayan snow-bed near Gangotri. After piercing the Himalayas it flows through the United Provinces of Agra and Oudh and Bihar and enters Bengal forming part of the western boundary of Malda District. Until some four hundred years ago its subsequent course was due south through Murshidabad District down the channel which takes the name of Bhagirathi. By degrees this channel silted up and became unequal to its task and the main stream of the Ganges was thus obliged to seek another outlet. In this way the Jalangi and the Mathabhanga became in turn the main stream. The river, however, tended ever eastwards until it was met and stopped by the Brahmaputra at Goalunda in the north-eastern corner of Faridpur District. From that point the two great rivers travel down a common channel and join the Meghna at the south-eastern corner of Dacca District. The portion of the main stream of the Ganges from the off-take of the Bhagirathi to the point where it joins the Meghna is known as the Padma. The Ganges or the Padma borders the districts of Malda, Rajshahi and Pabna in the Rajshahi Division, the districts of Murshidabad and Nadia in the Presidency Division and the districts of Faridpur and Dacca in

the Dacca Division. The Bhagirathi flows through Murshidabad District and receives the Jalangi opposite the old town of Nadia, and the Mathabbanga, a little below Santipur, and takes a course, generally south, past Calcutta, to the Bay of Bengal, separating the districts of Burdwan, Hooghly and Howrah in the Burdwan Division from the districts of Nadia and 24-Parganas in the Presidency Division. It is from a little above Santipur that the river takes the name of the Hooghly, the most westerly channel by which the waters of the Ganges enter the Bay of Bengal. According to Hindu belief, the Bhagirathi-Hooghly is called the Ganges and held sacred, the main stream (that is, the Padma) losing its sanctity. Another important distributary of the Ganges below the outlet of the Mathabhanga is the Garai and its continuation, the Madhumati; in the lower part of its course it is called the Baleswar and its estuary, the Haringhata. This river borders the districts of Nadia, Jessore and Khulna in the Presidency Division, and the districts of Faridpur and Bakarganj in the Dacca Division.

The Brahmaputra.—Having its source at no great distance from that of the Ganges, but on the other side of the Himalayas, the Brahmaputra

flows eastwards through Tibet where it is known as the Tsan-po until it reaches a point due north of the eastern extremity of Assam where it takes a southerly course, and after piercing its way through the eastern Himalayas emerges in the plains of Assam. It then turns westwards and, after traversing the Assam valley, enters Bengal from the north-east and first touches the province on the eastern border of Rangpur District. Formerly, the Brahmaputra flowed in a south-easterly direction across the Mymensing District to the Meghna just below Bhairab Bazar. It is now a dying river, as except in the rains it carries off but little water from the parent river, but is still dignified by the high-sounding title of the Brahmaputra. A still older channel, which also bears the name of the Brahmaputra, flowed past Nangalbund across the present channel of the Dhaleswari past Munshiganj finally falling into the Padma near Rajabari (Dacca District). About the end of the 18th century the main stream of the Brahmaputra began to change its course further to the west to join the Padma at Goalunda having been re-inforced by the Tista and having absorbed the lower reaches of the Jamuna, formerly a minor river, within its bed. The

lower section of the Brahmaputra from its entrance into the plains of Bengal to its confluence with the Padma is, however, given the name Jamuna. This river forms part of the eastern boundary of the Rajshahi Division and borders the districts of Rangpur, Bogra and Pabna in the Rajshahi Division and the districts of Mymensingh and Dacca in the Dacca Division.

The Meghna.—The name Meghna is given to the lower reaches of the Surma river which rises on the southern slopes of the mountain range forming the northern boundary of Manipur and carries down the drainage of the Surma Valley. It receives Old Brahmaputra near Bhairab Bazar and the mighty Padma at the south-eastern corner of Dacca District, and the united streams discharge their waters into the Bay of Bengal by several mouths separated by low silt-formed islands. The portion of the river from Bhairab Bazar down to the sea is called the Meghna and it borders the districts of Dacca, Faridpur and Bakarganj in the Dacca Division and the districts of Tipperah and Noakhali in the Chittagong Division and thus forms the boundary between the two divisions.

The principal rivers described above divide the province into five natural divisions:—

(1) The Burdwan Division lies on the west of the Bhagirathi-Hooghly. The rivers of this division are nearly all tributaries of the Hooghly, having their origin in the highlands of Chota Nagpur or the Tributary States of Orissa. There are some artificial canals, such as the Eden Canal, the Damodar Canal, the Midnapur Canal, etc., constructed for supplying water for drinking and irrigation purposes.

(2) The Presidency Division lies on the south and south-west of the Padma, and is separated from the Burdwan Division by the Bhagirathi-Hooghly on the west, and from the Dacca Division by the Madhumati-Baleswar on the east. This division is intersected by the distributaries of the Padma and their offshoots.

(3) The Rajshahi Division lies on the north of the Padma and west of the Jamuna and is watered by their tributaries and distributaries.

(4) The Dacca Division is separated from the Presidency Division by the Madhumati-Baleswar, from the Rajshahi Division by the Padma and the Jamuna, and from the Chittagong Division by the Meghna. This division is the meeting place of the three great rivers—the Padma, the Jamuna

and the Meghna—and is intersected by the subsidiary branches and tributaries of the great river system thus formed.

(5) The Chittagong Division lies on the east of the Meghna. The principal rivers which traverse this division either flow into the Meghna or enter the Bay of Bengal.

The Sundarbans, meaning literally the forests of sundari trees (*Heritiera littoralis*), extends along the coast of the Bay of Bengal, from the Hooghly on the west to the Meghna on the east through the districts of 24-Parganas, Khulna and Bakarganj, and runs inland for a distance of 60 to 80 miles ; it is intersected from north to south by large tidal rivers or estuaries which are connected by numerous interlacing channels, and the whole tract is a tangled network of estuaries, rivers and watercourses.

The numerous rivers and khals in Bengal are of use in many ways. They yield an ample supply of drinking water, ensure a plentiful supply of fish, serve as drainage and irrigation channels, form excellent waterways along which a great volume of passengers and goods traffic is carried cheaply and conveniently, and bring down vast quantities of fertilizing silt. It may be noted that silt is constituted by finer fragments of rocks.

The weathering of rocks furnishes loose materials of various sizes ; the loosened materials from the surface of rocks together with decayed organic matter are swept off the surface or down the hill slopes by the wash of rain and are carried down the rivers. The larger fragments are however soon dropped, but the finer earthy particles (*i.e.*, the silt) are carried along and distributed all around through the numerous rivers and khals. When the rivers and khals overflow their banks during the rainy season, the inundated lands receive a top-dressing of silt which is richer than the soils in plant food materials, being especially rich in potash (K_2O). The periodic inundation of lands serves also the purpose of purifying their surfaces by washing away decaying vegetable and animal matters and of purging the streams, ponds and ditches of insects and impurities many of which are harmful to man and beast.

During the past years the rivers and khals of Bengal have been steadily deteriorating as they are silting up either in their upper or lower reaches or throughout their courses. In the greater part of the province, most of the rivers and khals have shrunk to a mere fraction of their

[1] "Report on the Source, Supply and Agricultural Value of Silt in Burma," F J. Warth.

former volumes, and are moreover choked with water hyacinth. In consequence, they are no longer able to fulfil their old functions of supplying ample drinking water ; the fish supply is becoming scarce ; sanitary drainage cannot be effected through channels with glutted beds and blockaded mouths ; navigation at ease is rendered impossible, and as a result trading centres, which formerly thrived on account of their situation on the banks of active rivers, are now handicapped for inadequate traffic facilities ; and the soil has become less fertile than it was formerly for want of silt-laden waters. Generally speaking, the river system of the Burdwan Division is constituted by a few moribund streams, and the silt-laden waters are to a certain extent confined to the channel of the river by protective embankments ; the greater part of the Presidency Division is described as a land of dead (*i.e.*, silted-up) and dying rivers ; the Rajshahi Division is seamed with silted channels ; Eastern Bengal (Dacca and Chittagong Divisions) is still a land of comparatively active rivers and a large portion of this tract is subject to annual inundation and silt-fertilization.

The decay of the river system is one of the chief causes of the deterioration of public health,

more especially from an increase of malaria which is the greatest disease scourge of Bengal. It will be noted that malaria is caused by minute parasites, inoculated through the bites of certain species of anopheles mosquitoes which have previously become infected by sucking the blood of malaria patients. The spread of malaria in any locality is thus dependent upon the presence of malaria patients, the presence of other susceptible persons and the presence of certain species of anopheles mosquitoes. The general prevalence of malaria in each of the divisions is indicated by the fever index, that is, the number of new cases of malaria admitted for treatment to the dispensaries of a district for every 100 new admissions of all sorts.

Divisions.	Fever indices.	
	1868.[1]	1920.[2]
Burdwan	21·9	48·2
Presidency	17·3	45 9
Rajshahi	22·3	24·6
Dacca	9·3 (Dacca and Chittagong)	17·5 (Dacca and Chittagong together: 14·0)
Chittagong		13 1

[1] "Some Economic Aspects of Bengal Malaria," C. A. Bentley.

[2] Bengal Public Health Report for the year 1925.

This table shows that during the period from 1868 to 1920, malaria has increased very greatly in Burdwan, Presidency and Rajshahi Divisions. This increase is ascribed to a corresponding increase in the number and distribution of anopheles mosquitoes and malaria parasites. In these areas not only the decay in the river system but also the river embankment and a network of roads and railway lines have combined in various degrees resulting in the diminution of the normal amount of flood, interference with the free natural drainage of the country, and formation, by partial drying up of water after the rains are over, of pools of relatively stagnant rain water which favour the breeding of anopheles mosquitoes ; consequently, malaria has become very prevalent in these parts of the province. The Dacca and Chittagong Divisions are the least malarious area in Bengal. This is due to the fact that the supply of flood water leads to annual inundation, and as there are few protective and railway embankments, the water passes more or less freely over the country ; at the end of the rainy season, the river levels fall and the flood water flows away from the surface of the land leaving the soil well drained and healthy. The higher the flood, the greater is the consequent

flushing of the country and less the incidence of malaria.

For many years there has been an insistent demand for maintaining the integrity of the river system, reviving the decaying rivers with all their ramifications, and for constructing embankments, whether for roadways, railways or other purposes, in such a way that the natural inundation or drainage of the country is not interfered with. The Royal Commission on Agriculture in India recommended the appointment of a Technical Committee of experts to examine and report on the advisability of setting up a provincial Waterways Board in Bengal. The Government of Bengal appointed a committee of experts which recommended that a Waterways Board consisting of several Trustees representing commercial and public opinion should be created by statute to take over the navigable waterways of Bengal from the Irrigation Department and to administer and maintain them throughout the Presidency. The Committee's detailed recommendations were considered by the Government and their decisions have been embodied in the shape of an Act (the Bengal Waterways Act) which has been modelled in the line of the Calcutta Improvement Trust Act. The Government may declare which

of the navigable channels shall be controlled and administered by the Waterways Board. and the Board will assume the control and administration of these channels, clear, widen, deepen, divert or otherwise improve them, construct locks, sluices, wharves, etc., clear or destroy the water hyacinth in them, and do all other act necessary for improving them, and also make and open new navigable channels.

A short note on the "Water Hyacinth" (*Eichhornia speciosa*) may not be out of place. The water hyacinth (commonly known as *kachuri* in Bengali) is a native of South America. It is said that a certain person brought this from South America as an ornamental plant for tanks and lakes. There are other fables concerning it according to which it was introduced into this country by a jute merchant of Narayangunge from Australia, by a Dutchman from Holland, by a lady from England, and by a traveller from Persia. Whatever may be the source from which it was introduced into this country, the plant grows exceedingly rapidly and it has become a serious pest during the last few years as it has now spread over wide areas in Bengal with the result that in many places the waterways have been blocked, tanks choked and polluted and lands thrown out

of cultivation. It is not a Bengal, nor a Bengal-cum-Assam, problem ; it has become a curse in the United Provinces too, and is also found in Burma, Siam, Indo-China and everywhere else under similar geographical and climatic conditions. So far as Bengal is concerned, it should be noted that the lower districts cannot be freed until the upper districts are, and these cannot be until the United Provinces and Assam have got rid of the plant. The three provinces (Bengal, Assam and the United Provinces), therefore, seem called on to work in unison, and the Government of India too might find a place in the fighting line. Even if the pest cannot be eradicated without the help of other provinces, it can certainly be mitigated if unceasing battle is offered by all the forces that are immediately available. We cannot get rid of the water hyacinth by a magical spray or formula such as that invented by Mr. T. S. Griffiths. There is a growing feeling in Bengal in favour of legislation. Burma has an Act declaring the pest a public nuisance and punishing owners of land who fail to destroy it but the the plant has not disappeared. There is a general belief that the only thing to do is to manhandle it. Everybody must clear his own land by plucking out the plant by the roots and destroy it

by letting it dry in the sun and then burning it. The question of eradicating the water hyacinth pest from Bengal Waterways has been included in the Bengal Waterways Act in connection with the larger question of the maintenance of the waterways. It is interesting to note that in recent years the water hyacinth plant has been shown to be a potential source of wealth. Apart from the possibilities which occur to the technically-minded chemist and which may eventually be realised, such as the production of power gas, power alcohol, commercial potash, a compressed fibre such as "maizolite" or even artificial silk, there can be no question that by carefully collecting and composting it with cow-dung, wood ashes, and waste vegetable matters, this pernicious weed can be converted into a valuable manure.

Rivers and Khals as Sources of Water Supply.

Rivers and khals are the chief sources of water supplies in Bengal. In fact, people living near these sources, obtain their supplies almost universally from them. But owing to the decadence of rivers and khals during the past years, there is a great difficulty in obtaining drinking water in many places.

Rivers and khals carry along a considerable amount of suspended solids (*e.g.*, silt, etc.) and are contaminated with every conceivable abomination. They usually collect the drainage of the locality and contain decaying vegetable and animal matters that have accumulated on the tracts of land drained by them. The foreshore is, as a rule, misused and the water is further contaminated by boatmen's excreta, by the refuse from river crafts, by foul contents of municipal drains, and by sewage and waste products of manufactories built on the banks. One encounters corpses in the rivers and khals—from those of rats and fowls to those of drowned sheep and cattle, bodies of unwanted babies and of persons drowned by accidents. Sometimes the dead bodies are thrown into the river by people of nomadic habits. The water from these sources must therefore be considered unsafe for drinking purposes without some method of purification. During the course of flow of the rivers and khals, they undergo a certain amount of self-purification, no doubt, through the oxidation of organic impurities, sedimentation of suspended matters, and in other ways, but the water is never completely purified.

A river or a khal receives the supply of water partly from its own intake and partly from its

affluents. It is also fed by springs in its bed. The mineral ingredients of its water are therefore derived from the rocks of the land over which it and its feeders flow. The rivers of Bengal are also affected by the tide to a distance of about 100 miles inland from the sea. The ingress of sea water into the rivers having low levels and being greatly diminished in volume during the dry months causes brackishness of the water; during the rainy season the rivers bring down an immense volume of fresh water, and as a result, the admixture of sea water is proportionately much less than during the dry months and the brackishness is therefore not marked. Some rivers, particularly those in the Sundarbans, remain brackish practically throughout the year.

CHAPTER VI

Wells

A portion of the rain water sinks into the ground and continues to descend at a pace varying with the size of the interstices through which the water has to pass until it meets with an impervious stratum of clay or other non-porous formation, and rests upon that forming a reservoir of ground water. The surface water which may contain impurities is greatly purified as it percolates through the soil which, if not overburdened with organic matter, acts as an extensive filter bed. The ground water, as a rule, does not exist as a river or lake, but occupies rather the spaces between the sandy particles except in limestone formations. The upper surface of the ground water is termed the water table which does not remain constantly at the same elevation but fluctuates with the rainfall, temperature and other factors. If a well is sunk below the water table, the water will percolate and fill the cavity up to the surface of the water table. This is what we call a shallow well. Its depth varies

with the vertical distance of the impervious stratum from the surface of the earth. Beneath the impervious stratum just mentioned, we come upon other porous strata and in them supplies of water which have percolated downwards from distant points where these porous strata reach the surface and form the catchment areas for the rain. We tap this supply by sinking what is called a deep well, that is, a well which passes through a superficial porous bed and an underlying impermeable stratum to reach a water-bearing stratum below. The distinction between a shallow and a deep well is not, strictly speaking, a matter of depth; for what is known as a "shallow well" in one place may be deeper than a "deep well" in another place from the fact that in the latter case the impervious stratum may be near the surface.

The wells commonly found in Bengal are shallow wells. The sinker generally terminates his work on reaching the first available flow of ground water. The physical feature of the country has much to do with the question whether a tank or a well is to be dug. In the low-lying portions, the earth obtained by excavating a tank is required for preparing house-sites and the mud-plinth of the houses. The water-table also is

comparatively high and if a well is dug in such a place, the impure surface water has but little chance of being purified in its passage through the soil to the well, and the water in the well is consequently not fit for drinking purposes. Hence a tank is preferred to a well. Wells are thus unsuitable in certain areas, notably in the districts of Noakhali, Tipperah and Bakarganj. In other parts of the province where the water-table is comparatively low, good water can often be obtained by sinking wells, as in these cases the water has undergone purification to a large extent in its passage through a thick layer of the soil, provided great care is observed as to the cleanliness of the surroundings. Moreover, in certain places, owing to the porous nature of the sub-soil it becomes too expensive a matter to excavate tanks to a depth sufficient for providing a perennial supply of water. Hence a well is sunk on economical grounds also. In the Madhupur Jungle Tract running through part of Mymensingh and part of Dacca Districts and in the Barind area including portions of Malda, Rajshahi, Dinajpur, Rangpur and Bogra Districts of the Rajshahi Division, tanks are not suitable and wells are in almost universal use. Wells are also common in other parts of the Rajshahi Division (with the exception of the

hilly portions), and in parts of the Presidency and Burdwan Divisions.

In Bengal the wells are divided into two classes, namely, the *kaccha* well or *pat-kua* which does not involve any masonry work and the *pucca* or masonry well, called *indara*, which has its sides made water-tight. It is very desirable that the well is lined with brickwork laid in cement or other materials so as to be quite impervious to soakage from the surface immediately surrounding it. This impervious lining should extend down to the water-table. If the porous deposit in which the well is sunk is of considerable depth, the sides of the well for at least 20 feet should be made impervious, so that the rain water percolating from the surface must pass through at least 20 feet of soil before entering the well, and in its passage through the soil the organic impurities in the water will be to a large extent removed. In the case of deep wells, if the sides are properly steined with brickwork laid in cement as far down as the impervious stratum, surface waters and ground water resting upon this stratum are entirely excluded, and the well is freed from those sources of pollution which so often contaminate shallow well waters. The lining of the well is needed also to prevent the edges breaking in.

Cost.—The cost of sinking a well in any place depends upon the diameter of the well, the distance of the water table from the surface, the nature of the soil, the kind of the lining materials used and other factors. A rough idea of the cost of sinking a well may be obtained in the following manner:—

The well is generally circular, and the volume of a well

$$=\pi \times r^2 \times D$$

where, r=radius of the well in feet, and
D=depth of the well in feet.

The volume of a well of 4 feet diameter and 40 feet depth

$$=\pi \times (\tfrac{4}{2})^2 \times 40 \text{ cub. ft.} = \frac{22}{7} \times 4 \times 40, \text{ or } \frac{3520}{7} \text{ cubic}$$

feet.

When the thickness of the well-lining is 10 inches, the volume of the entire space to be excavated is equivalent to

$$\pi \times (2 + \tfrac{10}{12})^2 \times 40, \text{ or } \frac{63580}{63} \text{ cubic feet.}$$

Hence, the volume to be lined $= \left(\frac{63580}{63} - \frac{520}{7} \right)$,

or $\frac{31900}{63}$ cub. ft.

Thus,

(1) Earth-work (in excavation and removal) and the draining out of water—

$\frac{63580}{63}$ cub. ft. (@ Rs. 5 per 100 cub. ft.) ... Rs. 50·5 approximately.

(2) Cement working—

$\frac{31900}{63}$ cub. ft. (@ Rs. 40 per 100 cub. ft.) ... Rs. 202·5 approximately.

The cost of a well of the above size will thus approximate to Rs. 50·5 + 202·5 or Rs. 253.

There are other items of expenditure, *viz.*,

(*i*) The tops should be finished off to prevent the access of surface washings.

(*ii*) The surface for some distance should be concreted, or otherwise rendered impervious so as

to increase the thickness of the soil through which the water has to pass.

(*iii*) Pumping or other arrangements are to be made for drawing out the water. Quotation for pumps driven by hand or by power may be obtained from Messrs. Martin and Co., Burn and Co. and other Engineering firms at Calcutta.

Wells as Sources of Water Supplies.

The water level in the wells fluctuates with the seasons. In many places (for instance in Dinajpur) the wells may run dry in a rainless season. On the other hand, in Cooch-Behar, for example, it is not uncommon to see the wells overflowing during the rains. In some cases, as in Jessore District, the water from kaccha wells is not used for drinking purposes owing to religious scruples, or the water is not considered good. The well water is sometimes brackish and the people are driven to tanks or rivers for drinking water.

The shallow well may be situated near a dirty drain or an unclean latrine, cesspool, stable or cattle-shed, and the filthy contents gradually soak through the surrounding soil and mingle with the water in the well. So a spot should be selected as far removed from all sources of pollution as possible and the lining of the well must

be so constructed as to be quite impervious to soakage from the surface immediately surrounding it. On adopting such precautions, the surface water percolates through the intervening stratum instead of entering the well direct, and becomes more or less purified. Even when the well is lined with impervious materials, it occasionally happens that the wall is broken and out of repair, and the heavy rain washes foul substances in the soil, derived by soakage from manure-heaps, middens, privies, leaky drains or cesspools, direct into the well.

When the mouth of the well is below the level of the surface of the ground, the washing of the street and the foul contents of the drain, as well as the discharges of the animals can easily find their way into the well. To prevent contamination from impure surface-washings, the mouth of the well should be protected by a wall or coping carried up to a foot at least above the surface of the ground.

Straw, leaves and dust containing faecal matter and other filthy objects may be blown into the well. Dirty vessels and dirty ropes are frequently used for the purpose of drawing out water. Every well should therefore be covered

and provided with a pump. At least a permanent arrangement should be made in the matter of drawing out water without using indiscriminately any rope or vessel for the same.

It is often found that the well has not been cleaned out for years together. Consequently mud, broken pots, pieces of rope and other refuse collect at the bottom, and sooner or later stop the spring from which the water flows. As a result, fresh water cannot get into the well and that which it already contains soon becomes unfit for use.

Nowadays the practice of well-digging is rapidly falling into disuse in various parts of Bengal as tube wells are a satisfactory source of water supply and they can be installed at a less cost.

CHAPTER VII

Tube Wells

Tube wells are contrivances for obtaining underground water by means of borings. The bore hole is lined with galvanized iron tubes to prevent the sides from falling into it and to shut off the surface water which may be contaminated with organic matter. Tube wells have been produced by a comparatively slow process of evolution from the ordinary well. In Arabia and China they have been used from very early times, the pipes being often hollow palm trees and hollow bamboos respectively. In India several borings were made some fifty years ago with a view to obtaining a water supply from artesian sources. But it is only during the last fifteen years that tube wells have become a favourite source of drinking-water supply in various parts of Bengal and are making a steady progress.

A tube well is divided into three parts. The lower part, known as the strainer, consists of a

tube made of brass or copper, and it has very finely perforated sides; its construction should be so devised as to allow a free flow of water into it, and at the same time to preclude the fine particles of sand from getting access into it and thereby clogging the holes around it. The middle portion of the tube well is made up of a number of galvanized iron pipes jointed together; the pipes should be of substantial make and must be firmly jointed together so as to prevent the seepage of water into the tube. The upper part of the tube well is the pump by means of which the water is drawn from the well. There are pumps of various designs and they may be driven by hand or by power.

Tube wells may be shallow or deep. A deep tube well is sunk through an impervious stratum to an underlying water-bearing stratum the outcrops of which often lie at a long distance from the point from which the water is drawn. If the well taps a water-bearing stratum overlaid and underlaid by impermeable strata, it is spoken of as an artesian well, so called from the province of Artois in France where these wells are said to have been drilled for the first time. In artesian wells the water is forced upwards in virtue of its tendency to reach the subterranean water level in water-bearing

strata supplying these wells; if, however, the subterranean water level is higher than the top of the artesian well, the water spouts out at its mouth. In India "there is no artesian reservoir comparable to the Dakota Sandstone of North America or the regularly disposed basin of London and Paris." [1] So far as the geology of Bengal districts is concerned, it is worthy of note that, with the exception of a portion of the Rajshahi Division where it is part of the Himalayas, Hill Tipperah, the eastern portion of the Chittagong Division, and a few coal-bearing strata in the Burdwan Division, the province consists mainly of the alluvium of the Ganges and the Brahmaputra. In some of the western and northern parts, this alluvium is of a much older age than in the lower parts of the province; except this, practically no differentiation of the alluvium has been made geologically. The alluvial deposits are composed mainly of alternate strata of clay and sand of varying coarseness. Clay is impermeable to water, whereas sand is permeable and its permeability allows the

[1] Recent Artesian Experiments in India," by B. E. Vredenburg, Memoir of the Geological Survey of India, Vol. XXXII, Part I, p. 22.

water to flow away subterraneously to great distances from the point at which it enters. A well sunk in a stratum of sand may penetrate to considerable depths before meeting with water, but water nevertheless is usually found on approaching the lower part of the porous formation where it rests upon an impervious bed of clay; for here the water, unable to make its way downwards in a direct line, accumulates as in a reservoir and is ready to ooze out into any opening that may be made. The thickness of the clay and sand layers in relation to each other varies considerably, and the same or nearly the same thickness may not be found at even a few yards' distance. It will thus appear that conditions causing artesian flow exist to a certain degree in all alluvial deposits. In most tube wells constructed in the alluvial soils of Bengal, the water in the tube does not, however, overflow, but only rises to within a few feet of the surface and the water is raised to the surface by pumps. Some idea of the nature and thickness of the strata encountered in making bore-holes in different parts of Bengal may be formed from the following examples:—

(1) *The hole bored at Fort William during the years 1835-1840* [1]

Nature of strata.	Thickness (in feet).	Depth below ground level (in feet).
Surface soil, loose sand and clay ...	10	...
Clay of different varieties ...	115	125
Loose sandstone	5	130
Argillaceous marl	20	150
Arenaceous clay with weathered mica slates and nodules of hydrated oxide of iron	20	170
Calcareous clay ...	5	175
Coarse friable conglomerate ...	10	185
Micaceous clay ...	20	205
Soft sandstone ...	5	210
Ferruginous sand intermixed with clay ...	90	300
Fine loose sand with minute fragments of felspar and granite ...	25	325
Sandstone slightly aggregated ...	55	380
Shelly calcareous clay ...	5	385
Carbonaceous bed ...	10	395
Coarse conglomerate ...	86	481

[1] "Geology of India," by H. B. Medlicott and W. T. Blanford, Part I, p. 399.

(2) *Boring at Canning (1887)* [1]

Nature of strata.		Thickness (in feet).	Depth below ground level (in feet).
Black earth ...	...	6	...
Clay of different varieties	...	49	55
Grey sand ...	...	71	126
Clay of different varieties	...	40	166
Yellow earth ...	...	7	173
Yellow micaceous sand ...	...	87	260

(3) *Boring at Jessore (1926)* [2]

Surface clay ...	...	14	...
Fine sand ...	...	6	20
Clay ...	...	51	71
Sand ...	...	21	92
Wood ...	...	2	94
Sand ...	...	8	102
Clay with sand ...	...	20	122
Sand (yellow and grey) ...	...	41	163
Coarse sand ...	...	62	225

[1] "Recent Artesian Experiments in India," by B. E. Vredenburg, Memoir of the Geological Survey of India, Vol. XXXII, Part I, pp. 44-45.

[2] The boring was conducted under the supervision of the Bengal Public Health Department, Engineering Branch.

(4) Boring at Jhargram, Midnapur District (1926)[1]

Nature of strata.	Thickness (in feet).	Depth below ground level. (in feet).
Black earth ...	4	...
Clay of different varieties	19	23
Kankar ...	9	32
Clay ...	11	43
Fine sand ...	3	46
Clay of different varieties	12	58
Sand mixed with gravel	2	60
Coarse sand ...	27	87

(5) Boring at Rajshahi (1924)[1]

Surface earth	12	...
Clay of different varieties	20	32
Fine sand	13	45
Clay of different varieties	20	65
Sand	115	180

[1] Borings were conducted under the supervision of the Bengal Public Health Department, Engineering Branch.

(6) *Boring at English-Bazar, Malda District (1926)*[1]

Nature of strata.		Thickness (in feet).	Depth below ground level (in feet).
Fine sand mixed with earth		10	...
Clay	...	40	50
Coarse sand	...	40	90
Quicksand	...	25	115
Coarse sand	...	15	130
Quicksand	...	47	177
Coarse sand	...	23	200
Fine sand	...	8	208

(7) *Boring at Bogra*[1]

Surface earth	...	8	...
Clay	...	12	20
Coarse sand	...	82	102
Clay	...	18	120
Fine sand	...	50	170
Clay	...	90	260
Fine sand	...	12	272
Stone with clay	...	82	354

[1] Borings were conducted under the supervision of the Bengal Public Health Department, Engineering Branch.

(8) Boring at Patuakhali (Bakarganj District) in 1923[1]

Nature of strata.	Thickness (in feet).	Depth below ground level. (in feet)
Surface soil ...	... 11	...
Clay ...	... 8	19
Fine sand ...	... 197	216
Slightly coarse sand	... 55	271
Clay of different varieties	... 98	369
Coarse sand ...	... 26	395
Clay mixed with pebbles	... 4	399
Slightly coarse sand	... 47	446

(9) Boring at Faridpur [1]

Surface clay	... 30	...
Clay of different varieties	... 94	124
Sand with clay	... 9	133
Fine sand ...	... 26	159
Medium sand ...	... 28	187
Sand with wooden chips	... 3	190
Medium sand ...	... 7	197
Fine sand ...	... 7	204
Medium sand ...	... 8	212
Coarse sand ...	... 27	239

1 Borings were conducted under the supervision of the Bengal Public Health Department, Engineering Branch.

(10) Boring at Comilla [1]

Nature of strata.	Thickness (in feet).	Depth below ground level (in feet).
Surface clay	15	...
Fine sand mixed with clay	7	22
Sand (yellow and grey) ...	49	71
Coarse sand	20	91
Clay mixed with sand ...	6	97
Coarse sand	23	120
Sand mixed with clay ...	15	135
Coarse sand	75	210
Gravel	7	217
Fine sand	6	223
Coarse sand	28	251
Gravels mixed with sand ...	12	263
Coarse sand	47	310
Fine sand	17	327

[1] The boring was conducted under the supervision of the Bengal Public Health Department, Engineering Branch.

according to the nature of the strata, quantity of the water required and the quality of the water met with. The sinker may reject layer after layer of unsuitable water-bearing strata until he reaches the right sort of the stratum, bearing plenty of water and cut off from the upper pervious layers by a thick layer of impervious material. In Bengal, a depth of 100 feet may be quite sufficient in some places, while in others depths of 700 feet or upwards may be required; in the Presidency Division and the delta of lower Bengal, a depth of about 200 feet is often sufficient.[1] In Australia, many borings are carried down to depths varying from 2,000 to 4,000 feet or over to tap the underlying water.[2] The deepest drilled well in the world is that at Athens, California, which has been constructed to a depth of 7,591 feet.[3]

In this country, "the water-jet system of boring" and "boring with Martin's sludger" have become very useful for sinking deep tube wells in soft, unconsolidated alluvial deposits.

[1] A pamphlet on "Tube Wells" issued by the Bengal Chemical and Pharmaceutical Works, Ltd.

[2] "Tube Well and its Irrigational Possibilities," by F. H. Vick, Agricultural Journal of India, XI, 1916, p. 296.

[3] "Water Supply Engineering," by H. E. Babbit and J. J. Donald.

The water-jet system of boring may be briefly described in the following manner:—

A hole is excavated a few feet down and the casing pipe provided with a cutting shoe on the lower end is fixed vertically in position. Within this casing pipe, a length of the water pipe, which is fitted with a nozzle at its lower end gradually tapering to an orifice of $1\frac{1}{4}$ inches diameter, is suspended from the pulley of the tripod in such a manner that the nozzle is kept about six inches above the bottom of the casing pipe. Chlorinated water is pumped under pressure down the water pipe so that it passes up the casing pipe and then overflows at its top. When the water jet impinges on the bottom of the bore hole, the subsoil is loosened, broken up and carried up by the ascending water overflowing at the top of the casing pipe. As the subsoil is thus washed out, the casing pipe is rotated to force it down and the water pipe is lowered to maintain a distance of a few inches only between the nozzle and the bottom of the boring. As both water and casing pipes are lowered, they are extended by screwing additional pieces on to their top ends. The joints must be properly made so as to be absolutely watertight. After the desired depth has been reached, the water tube is withdrawn and the

tube well put down. The space between the well pipe and the bore hole is next properly filled up with cement so as to prevent the contaminated surface and subsoil water from finding its way into the pure deep water around the end of the pipe. Finally, the casing pipe is pulled up, and the tube well is provided with an impervious platform at ground level sloping away from it and of a radius of at least 8 feet. The well should be vigorously pumped for a few days to draw away the sand immediately near the strainer and leave nothing but coarse gravel stones.

The system of boring with Martin's sludger is practically the reverse of the water-jet system of boring. "A cross or S chisel is attached to the lower end of the jet pipe, in place of the nozzle, and the sludger is screwed to the upper end of the pipe and secured to the rope passing over the pulley of the tripod. A reciprocating motion is given to the boring tools and a liberal supply of water poured frequently into the bore tube. The sand or other materials forming the subsoil is pumped out along with the water through the pipe and sludger." [1]

The driven tube well is also called the Abyssinian tube well as it was largely used during the

[1] Further Notes on Tube Wells," by T. A. Miller Brownlie.

Abyssinian campaign. It consists of a galvanized iron tube (about 6 feet long and $1\frac{1}{4}$ or $1\frac{1}{2}$ inches in diameter) perforated with small holes for the entrance of water. A layer of fine copper or brass gauze is wrapped round it so as to act as a straining material. One end of this tube is provided with a steel driving point, and the tube is vertically driven into the ground. Before it has altogether disappeared into the ground, another piece of galvanized iron tube is screwed on and this is also driven in. Successive lengths of tubes are attached until the water-bearing stratum is reached. The pump should be attached after every 5 feet has been driven and a trial made for obtaining the water. The driven tube well is most suitable where the water table is not very far from the surface and where the soil is soft or granular so as to be easily penetrated. It is scarcely practicable to drive the tubes deeper than about 30 feet, the sinker taking his chance in hitting a water-bearing stratum. Even when a water-bearing stratum is reached, there can be little choice in its selection, and nothing is really known about the capacity of the well to supply water. Unless it is sunk to great depths of coarse sand, a copious supply of water is rarely available. The water of shallow tube wells may

have undergone some degree of natural filtration and purification, but this cannot be relied upon as having been complete or sufficient.

Cost of Tube Wells.

The cost of sinking a tube well depends upon several factors, *viz.*, the nature of the strata encountered, the depth drilled, the diameter of the well, and the type of tubes, strainers, pumps, etc., used. The construction is usually done on contract by contractors who are skilled in this kind of work and have their own casing pipes and drilling equipments. Consequently, the freight of the materials to be conveyed to the place where the tube well is to be sunk and the travelling expenses of the boring mistries must also be taken into consideration. Thus the cost of a tube well varies very greatly and each case has to be dealt with on its merits.

The driven well is the cheapest form of tube well. The approximate cost of a $1\frac{1}{2}$ inches driven tube well, 30 feet deep, is as follows:—

	Rs.	A.	P.
1 driving point along with the strainer ($1\frac{1}{2}'' \times 6$ ft.) ...	13	0	0
4 pieces ($1\frac{1}{2}'' \times 6$ ft.) of galvanized iron pipe (Stewart and Lloyd) @ 8 as. per foot ...	12	0	0
4 sockets ...	1	8	0
1 pump (Pitcher-spout type) ...	9	8	0
Labour charges @ 8 as. per foot ...	15	0	0
Total ...	51	0	0

The above estimate is for the tube well to be driven at Calcutta. In other areas, the fares of the mistries and freights of the materials must also be added to this estimate.

An estimate of the cost of a drilled well may be made in the following manner assuming that it is to be installed at Calcutta and a depth of 200 feet is sufficient :—

	Diameter of the well		
	1½″ (yielding approximately 500 gallons per hour)	2″ (yielding approximately 1,000 gallons per hour)	2½″ (yielding approximately 1,500 gallons per hour)
	Rs. A. P.	Rs. A. P.	Rs. A. P.
200 ft. galvanized iron pipes (Stewart and Lloyd) ...	78 2 0 (@ 6 as. 3 p. per foot)	103 2 0 (@ 8 as. 3 p per foot)	159 6 0 (@ 12 as. 9 p. per foot)
11 sockets ...	4 2 0 (@ 6 as. per piece)	5 2 6 (@ 7 as 6 p. per piece)	9 10 0 (@ 14 as. per piece)
1 American brass strainer (Wall and Warth), 6 ft. long ...	13 0 0	21 0 0	30 0 0
1 Deming Pump ...	25 0 0	28 0 0	32 0 0
Labour charges (sludger method) ...	100 0 0 (@ 8 as. per foot)	150 0 0 (@ 12 as. per foot)	200 0 0 (@ Re. 1. per foot)
Total ...	220 4 0	307 4 6	431 0 0

When the water-jet system of boring is employed, labour charges become 4 to 6 times of those demanded in the sludger method.

Nowadays skilled labour is available in nearly all parts of Bengal for the sinking of tube wells of smaller sizes and the labour charges are now much lower than they were a few years ago. As the number of contractors increases, the charges demanded by them will be still lowered. Some District Boards and Union Boards have their own boring mistries and sink tube wells at a cost much below what contractors charge for similar work. For deep tube wells of greater capacities for town supplies, factories, irrigation, etc., it is necessary to consult reputed firms dealing with the sinking of tube wells such as the Bengal Chemical and Pharmaceutical Works, Ltd., W. Leslie and Co., Scott, Saxby and Co, etc. Mr. J. Vardon, Executive Engineer, North Western Railway, has worked out the ratio of the cost of masonry wells to tube wells of equal yield as 3·15 to 1·00, and has supplied the cost of some tube wells installed on the North Western Railway; the cost varied according to locality and other conditions as shown by the following examples [1] :—

1 "Tube Wells on the North Western Railway," by J. Vardon; Technical Paper No. 261 of the Railway Board, India.

Depth of the tube well.	Yield per hour (in gallons).	Cost (excluding supervision charges, carriage charges and trial boring charges).
		Rs.
158′	4,000	4,050
179′ 7″	8,000	6,004
338′	8,000	6,498
285′ 6″	10,000	7,618
164′	11,000	4,682
286′	11,250	12,044
245′	20,000	9,170
206′	25,000	7,663
278′ 6″	30,000	9,128
287′ 6″	30,000	9,949
345′	30,000	15,457
356′	30,000	13,217
251′	40,000	9,459

Deep Tube Wells as sources of Water Supplies in Bengal.

Deep tube wells, if properly constructed (that is, if the joints are perfectly watertight, the water used in the construction is thoroughly

sterilised so as to prevent contamination of the water in the well, and the space between the water pipe and the bore hole is properly filled with cement so that the surface water is entirely cut off), provide large quantities of clear water of a very high degree of organic purity. In fact, the water is often practically free from bacteria and requires no further treatment. This is due to the fact that the water has undergone perfect filtration in its passage through the soil since it fell as rain on the surface of the earth; for the outcrops of the water-bearing strata may be many miles from the spot at which the well is sunk. Generally speaking, the water supplied by deep tube wells in Bengal is rather hard and more or less brackish. Unless the water is unduly hard and brackish, it can be safely used for drinking purposes. The salinity of deep tube well water is due to either or both of the following causes:—(1) the water-bearing stratum may be impregnated with salt, (2) the water-bearing stratum may outcrop under the sea or under tidal rivers or khals or swamps so that the saline water percolates into the well. Consequently, it is highly desirable to locate deep tube wells as far away as possible from tidal rivers or swamps. It is interesting to note that at Canning

in the Sundarbans a boring was carried to a depth of 260 feet in the hope of getting a supply of fresh water for drinking purposes, as the water in the tidal creeks and rivers is almost always brackish ; at a depth of 55-126 feet, there was a stratum of grey sand full of salt water, but at a depth of 173-260 feet from the surface a stratum of yellow micaceous sand was struck containing perfectly fresh water.[1] At Patuakhali (Bakarganj District) on the other hand, the boring was continued to a depth of 550 feet but was abandoned as the water obtained was brackish and unfit for drinking. Tube wells are also unsuitable in ferruginous soils. Occasionally the water supplied by tube wells contains undesirable amounts of iron derived from the iron pipe on account of the presence of excessive amounts of carbonic acid gas which has characteristic ferro-solvent property.

Deep tube wells have proved successful in the greater portion of the alluvial soils in Bengal. As there is little risk of contamination, and, if the tube is a small one, the cost is much lower than that of digging a tank or constructing a masonry well, the tube well is the most hygienic

[1] "Recent Artesian Experiments in India," Memoir of the Geological Survey of India, Vol. XXXII, Part I.

and appropriate source of water supply in rural areas. In consequence, deep tube wells are being rapidly multiplied by District Boards and Union Boards in areas where they can be successfully installed. The District Boards of Bogra, 24-Parganas, Faridpur, Jessore and Hooghly have shown the greatest activity in sinking tube wells. In urban areas too there is a certain reaction against the method of water supply from rivers or tanks after filtration in favour of tube wells which have been adopted by several municipalities as an original or supplementary source of water supply. In fact, nowadays most of the water supply schemes coming to the Sanitary Board for administrative sanction are based on deep tube wells of large bore. The municipalities of Jessore, Faridpur, Comilla, Brahmanbaria, English Bazar and a large number of municipalities in the Presidency Division are supplied with tube wells. The water from tube wells may be pumped into an overhead reservoir from which it will gravitate through the distribution mains to street hydrants and home connections. A large number of tube wells have been installed at Calcutta and adjoining suburbs on account of municipal supplies being insufficient to meet requirements. The majority of the jute

mills and factories on both sides of the river Hooghly from Budge-Budge to Kanchrapara now draw their drinking water from tube wells. Many of the railway stations in Bengal are now supplied with water from tube wells.

Irrigation by tube wells is a comparatively recent development. There are great tracts of land which the monsoon floods cannot reach; again, even when the lands are inundated during the rains, the moisture-content may not be sufficient for growing cold weather crops. The solution of the problem of irrigating these areas lies mostly in the sinking of tube wells which are capable of supplying water all the year round, provided the water-bearing stratum is not depleted.

The tube well labours under one disadvantage. The pump is apt to get out of order and there is no certainty when it will cease to be useful. This disadvantage can be prevented if the services of a mechanic capable of attending to repairs can be easily secured at reasonable cost. The provision of tube wells on a large scale by municipalities, District Boards and Union Boards is useless without the employment of a small staff to supervise them and to repair the pumps.

It is not definitely known how long a tube-well will last. Tube-well waters are sometimes highly corrosive on account of the presence of a large amount of carbonic acid gas, and big holes in the tubes have actually been observed when some tube wells were detached.

CHAPTER VIII

Springs

A spring is a stream of water emerging from the ground. Springs are usually divided into two classes, surface springs and deep-seated springs, corresponding fairly closely with shallow and deep wells. The portion of the rain water that sinks through a porous rock is eventually stopped by an impermeable stratum and accumulates along its surface until it issues as a spring in a valley or the side of a hill at a point where the impermeable stratum which holds the water rises to the surface. This is called a surface spring. It often ceases to flow in the dry season. A deep-seated spring is due to the presence of a fissure in the impervious stratum, which enables the water below it to rise to the surface. This may be considered as a natural deep well outcropping where the geological formations are favourable for it. Deep-seated springs also may be found either in a valley or at a considerable height on a hill and are usually perennial.

In Bengal numerous springs are found in the hilly portions of Darjeeling District and the people in these areas depend almost exclusively upon the spring water for domestic and irrigational

purposes. Many of the springs in Darjeeling District dry up in the cold weather months, but the great majority of them are perennial, their volume increasing during the rains. The water supplies of Darjeeling town are derived from about 30 perennial springs on the western flank of Senchal. The town of Kurseong is also supplied with water from 15 springs on Dow Hill and a number of springs in the forest of Sepoydhura. The town of Kalimpong is dependent for water supplies partly upon springs and partly upon the Rilly river. Springs are found also in the districts of Jalpaiguri, Chittagong, Bankura and Birbhum.

Springs as Sources of Water Supply.

In the case of deep-seated springs, the water has percolated through a considerable depth of porous strata and has thus undergone a process of filtration and natural purification which is often entirely perfect; as a result, the organic impurities are oxidised and the water becomes clear and sparkling, the clearness being due to the removal of suspended matter owing to thorough filtration and the sparkle being caused mainly by the presence of carbonic acid gas in solution. In fact, the water of deep-seated springs is often

sufficiently pure to require no further treatment. Surface springs are more liable to accidental pollution than deep-seated springs, as in the former case the overlying porous layer of soil may be too thin to remove the impurities derived from surface washings from privies, stables, etc. Soil pollution in the neighbourhood of springs must therefore be prevented. To guard against contamination, it is necessary that the surface of the soil around the point of delivery of a spring is walled in and the water conducted to the surface by a short pipe. The mineral contents of the spring water depends upon the nature of the strata through which the water has percolated; for instance, the water passing through primary rocks (*e. g.*, gneiss, as in Darjeeling) is very soft, whilst that derived from secondary formation (*e.g.*, limestone, dolomite, etc.) is more or less hard.

Mineral springs.—[1] A large number of spring waters are classed as mineral, not because the

[1] References :—

(1) "British Spas and Seaside Resorts"; Official Handbook of the British Health Resorts Association.

(2) "Squire's Companion to the British Pharmacopoeia."

(3) "Materia Medica"—by W. Hale White.

(4) "A Text-book of Inorganic Chemistry"—by J. N. Friend and D. F. Twiss, Vol. VII, Part I, p. 206.

total quantity of foreign matter in solution is excessive, but rather because they contain an unusual amount of some particular constituent in solution which gives the water a marked taste, or some specific property. Mineral springs are often named according to some special constituents in them. Thus—

(*i*) Arsenical springs—

Arsenic is found in some French springs. The Bourboule spring water contains sodium arsenate (about 0·16 grain per pint) and other salts. Arsenical water is used in certain forms of anaemia and in asthma.

(*ii*) Carbonated springs—

The water holds a large quantity of carbonic acid gas in solution ; *e.g.*, Ems water in Germany containing over 500 volumes of carbonic acid gas per 1,000 volumes and sodium bi-carbonate (about 18½ grains per pint), calcium and magnesium bi-carbonates, and other salts ; the water is alkaline and beneficial in dyspepsia, gout and certain forms of kidney diseases ; the dissolved carbonic acid gas acts as a mild gastric sedative.

(*iii*) Chalybeate springs—

They contain ferrous bi-carbonate in solution ; *e.g.*, Pyrmont water in Waldeck, Schwalbach water in Germany and Spa water in Belgium containing ferrous bi-carbonate ($\frac{1}{5}$ to $\frac{1}{2}$, $\frac{1}{2}$ to $\frac{3}{4}$ and $\frac{1}{2}$ to 1 grain per pint respectively) and other salts. Chalybeate waters are useful as general tonics in anaemia and debility.

(*iv*) Lithiated springs—

They contain salts of lithium ; *e.g.*, Buffalo Lithia (Mecklenburg Co., Va., U.S.A.) waters. There are three springs of which the spring No. 2 is the most important containing lithium bi-carbonate (about $2\frac{3}{4}$ grains per pint) and other salts. Lithium bi-carbonate is useful in gout.

(*v*) Muriated springs—

They contain sodium chloride with varying amounts of the chlorides of potassium, calcium and magnesium. Two of the Cheltenham springs in Gloucestershire, namely, Pitteville and Lansdown springs, are characterised by their high content of sodium chloride (about $58\frac{1}{4}$ and 49 grains of sodium chloride per pint respectively) ;

" Edelquelle " spring at Reichenhall (Bavarian Alps) contains chiefly sodium chloride (about 2,150 grains per pint). Very concentrated hot brine baths are used for many forms of rheumatism.

(*vi*) Sulphated springs—

They contain sulphates, chiefly the sulphates of sodium and magnesium. Sodium sulphate is the chief constituent of Carlsbad and Marienbad waters in Bohemia, and it occurs associated with much sulphate of magnesium in spring waters at Friedrichshall and Hunyadi Janos in Buda-pest. The amounts of these substances in them are shown as follows:—

	Amount of sodium sulphate (per pint).	Amount of magnesium sulphate (per pint).
Spring water at Carlsbad ...	21 grains	—
Spring water at Marienbad ...	44-45 grains	—
Spring water at Friedrichshall ...	58 grains	49 grains
Spring water at Hunyadi Janos ...	155 grains	150 grains

Sulphates of sodium and magnesium are powerful purgatives. Sulphated waters are therefore

especially useful for habitual constipation. Sodium sulphate is a cholagogue too, and sufferers from gallstones are undoubtedly benefited by a course of waters containing sulphate of sodium, and therefore frequently go to Carlsbad.

(*vii*) Sulphuretted springs—

They are characterised by the presence of sulphuretted hydrogen gas and alkaline sulphides such as sodium sulphide; *e. g.*, the sulphuretted springs at Aix-les-Bains (in Savoy, France), Aix-la-chapelle (Germany) and Harrogate (England). The strong sulphur waters at Harrogate contain 37 volumes of sulphuretted hydrogen gas per 1,000 volumes and also sodium sulphide (about 15 grains per gallon) and other salts, and are believed to stimulate the secretion of bile. In fact, sulphuretted waters have considerable reputation for hepatic disorders. Baths in sulphuretted waters are considered to be very useful for rheumatic, gouty and skin affections.

Radium or radio-active materials have been discovered in the springs at Bath and Buxton in England and in numerous other springs in many places in Europe, America and elsewhere. Many of the curative properties of mineral spring water may be either due to, or enhanced by, the presence of radio-active substances (which are

said to possess the power of eliminating toxins from the human body and stimulating normal healthy metabolism), and this would account for the well-known fact that artificially prepared mineral waters do not always possess the same medicinal values as the natural waters. The waters of some springs, as those at Aix-là-chapelle, Baden-Baden (Germany), Bath (Britain), Carlsbad, Ems, etc., issuing from great depths are warm or even hot. This is due to the fact that there is a rise of temperature from the surface of the ground downwards at the rate of 1°F. for about 60 feet of descent on an average. The springs of hot water are known as thermal springs, and baths in thermal waters, combined with various forms of massage and exercise, are used in the treatment of chronic rheumatism, chronic gouty disorder and other maladies.

In Europe and America famous spas have grown up on the sites of mineral springs. There are quite a large number of mineral and thermal springs scattered over different parts of India also and vast possibilities are open for the treatment of certain diseases. But they are almost totally neglected and nothing is done for their development. In Bengal there is a mineral spring near Buxa (in the district of Jalpaiguri)

about 3 miles from Tashigaon, where Bhotias suffering from skin-diseases go and bathe.[1] In the district of Darjeeling, there was a mineral spring about 3 miles east of Darjeeling town, which gave its name to "The Mineral Spring Tea Estate." It was formerly used for medicinal purposes and a convalescent depot was built near by for the convenience of the troops stationed at Jalapahar. It was also used by the hill people for rheumatism and cutaneous diseases. At present there is no trace of it in the Mineral Spring Tea Estate, and its mysterious disappearance is believed to be associated with the disastrous land-slip of 1899 caused by a violent cyclone with heavy rainfall. A list of other mineral and thermal springs occurring in Bengal is given below: [2]—

Darjeeling—

(*a*) Mechi (26° 50′ 0″, 88° 30′ 0″). The water is said to be efficacious for rheumatism and skin diseases.

(*b*) Minchu (27° 6′ 0″, 88° 10′ 0″)—5 miles from Darjeeling town. The water is said to be efficacious in cases of gout, rheumatism, etc.

[1] Jalpaiguri District Gazetteer.

[2] "Mineral Waters of India—By K. S. Ray," Journal of the Indian Medical Association, February, 1932.

Birbhum—

There is a group of hot springs (128°-162°F.) on the right bank of the Bakreswar stream, a mile to the south of Tantipara (23° 54′ 30″, 87° 26′ 0″). The water is impregnated with sulphuretted hydrogen gas.

Chittagong—

(*a*) Babu or Bharat Kund—The water is chalybeate and sulphuretted.

There are 8 other springs within a circuit of 6 miles:—

(*b*) Balwa Kund—The water is diuretic and slightly aperient.

(*c*) Naulakha Kund—The water is warm and saline.

(*d*) Kauri Kund—The water is hot, saline, sulphuretted and chalybeate.

(*e*) Dadhi Kund—The water is saline.

(*f*) Brama Kund—The water is very hot, slightly chalybeate and somewhat saline.

(*g*) Chandra Kund—The water is hot and saline.

(*h*) Suraj Kund—The water is hot and saline.

(*i*) Sita Kund—The water is tepid and pure.

CHAPTER IX

CHARACTER OF DIFFERENT WATERS

To the ancient philosophers water was an elementary substance. It was Cavendish who in 1781 showed that water is the product of the chemical union of two elements, hydrogen and oxygen. It is represented by the formula H_2O indicating that it consists of two volumes of hydrogen united to one volume of oxygen. As a matter of fact the molecule of water is much more complex. According to H. E. Armstrong aggregates of four, five or six H_2O molecules probably exist in water ; aggregates of six probably confer upon ice its hexagonal crystalline structure ; dry steam has the molecular formula H_2O, whilst saturated steam is constituted partly of aggregates of two H_2O molecules.[1] In recent years, "heavy water" has been prepared by the chemical union of "heavy hydrogen" (*i.e.*, the heavier of the two isotopes of hydrogen) and oxygen which, in turn, consists of three isotopes.

[1] King Zett's Chemical Encyclopaedia, 5th edition.

Absolutely pure water is probably unknown on account of its power of dissolving, to a greater or less extent, practically everything with which it comes into contact. Water, as it exists in Nature, contains in various degrees suspended and dissolved materials derived from the atmosphere and from the earthy strata traversed by it. Suspended matters consist mainly of clay and organic matter including microscopic bodies—bacteria, algae, protozoa, etc.—living or non-living. Substances which become dissolved in natural waters are of various kinds such as carbon dioxide, oxygen, nitrogen and other gases, mineral salts (*e.g.*, bi-carbonates, carbonates, chlorides, sulphates and nitrates of calcium, magnesium, sodium and potassium, and other salts) and organic matters of both vegetable and animal origin (*e.g.*, urine, soluble portions of faeces, and the products of decomposition of vegetable and animal bodies). The suitability or otherwise of a natural water for a particular purpose depends on the amount of these materials contained in it. For the large majority of manufacturing requirements, a mineral analysis of the proposed water supply, together with its physical appearance, will suffice to indicate whether it is fit for the purpose in view. The quality of a water to be

used for drinking purposes is judged from joint considerations of the data supplied by a sanitary analysis (which includes a physical examination, a sanitary chemical analysis, a bacteriological and a microscopical examination), sanitary survey of the water shed and clinical results.

Physical examination—

In the physical examination, the water is looked at, tasted or smelt to determine whether it possesses any colour, turbidity, taste and smell. A potable water should be practically colourless (when viewed in small quantities) and free from turbidity, and it should be devoid of taste and odour.

Chemical analysis—

The principal tests made in the sanitary chemical analysis are given below:

(*i*) *Total solids.*—The amount of total solids or residue left after evaporation of a given quantity of water to dryness furnishes an index of the total quantity of mineral and organic matter held by the water in suspension and solution. This amount varies considerably with the particular

source of the water :—

Sources of water.	Total solids (Parts per 100,000).
Spring water at Darjeeling ...	3—4
Water from a tank at Sandwip ...	8
Water from a tank at Santipur ...	30
Hooghly river water (in January and February)	100 (approx.)
Hooghly river water (in September and October)	150 (approx.)
Water from a tube well at Jalpaiguri ...	16
Water from a tube well at Chandpur ...	240
Water from a tube well at Budge-Budge ...	420

It should be noted that the bulk of the total solids in river water, particularly in the rainy season, is often formed by suspended solids; spring and tube-well waters are, however, practically free from suspended matters.

(*ii*) *Hardness.*—By a "hard water" is meant a water holding in solution certain salts, chiefly the salts of calcium and magnesium, which destroy soap without producing a lather. Soap consists of the sodium or potassium salts of organic acids (*e.g.*, palmitic acid, stearic acid and oleic acid) derived from fats and is soluble in

pure waters. In the presence of calcium and magnesium salts, the soap is decomposed and an insoluble curdy precipitate is formed by the union of the organic acids of the soap with the calcium and magnesium salts. Until the whole of the calcium and magnesium salts have in this way been thrown out of solution, no lather can be obtained, and the soap is useless as a cleansing agent; but as soon as this point is reached, the addition of any further quantity of soap at once raises a lather on the water and the soap is capable of acting as a detergent. One grain of calcium carbonate wastes about 8 grains of soap before a lather can be produced. The hardness of water or its "soap-destroying" power, whether due to calcium or magnesium compounds or other agents, is calculated as the equivalent of so many parts of calcium carbonate per 100,000 parts of water. A water having a hardness of less than 5 parts per 100,000 is usually considered very soft, as it lathers freely with soap; 5-10 parts of hardness, fairly soft; 10-15 parts of hardness, slightly hard; 15-20 parts of hardness, moderately hard; 20-30 parts of hardness, hard; over 30 parts of hardness, very hard.

The hardness may be temporary or permanent. Natural water holds carbonic acid gas in solution

As it passes through calcareous soil or through lime stone or magnesium rocks, the carbonic acid gas present in it dissolves the *carbonates* of calcium and magnesium, forming soluble bi-carbonates. The hardness of water produced by these bi-carbonates is called "temporary" because on boiling the water, the carbonic acid gas is driven off and the soluble bi-carbonates are precipitated as insoluble carbonates. The presence of chlorides and sulphates of calcium and magnesium derived from the soil produces what is called "permanent" hardness, because these salts are not precipitated by boiling. *Hard water* is undesirable more from economic than from sanitary standpoints. It causes a waste of soap in washing, produces "boiler scale" which impedes the passage of heat from the fire to the contents of the boiler and thus causes a waste of fuel, and is objectionable in some industries. It is also undesirable in cooking meat or vegetables, as a certain amount of hardness-producing materials is deposited on their surfaces which either hinders the proper penetration of the heat into the interior, or prevents solution of the soluble materials when this is desired.

The amount of hardness-producing constituents in a water depends upon the character of

the soil with which the water has been in contact, the length of exposure, and the amount of carbonic acid gas in it. In Bengal, the spring water in Darjeeling is extremely soft; the tank water is usually fairly soft or slightly hard; the river water in the rainy season is usually fairly soft or slightly hard, but in the dry season, especially in April and May, it often becomes moderately hard or hard. The hardness of tube-well waters varies within wide limits. The following table illustrates the variations in the hardness of water:—

Sources of water	Hardness (Parts per 100,000)		
	Temporary.	Permanent	Total.
Spring water at Darjeeling	0·5	0·5	1·0
Water from a tank at Sandwip ...	1·0	1·0	2·0
Water from a tank at Santipur ...	8·0	12·0	20·0
Water of the Teesta river at Teesta Bridge, (Darjeeling) ...	0·5	1·0	1·5
Water of the Hooghly river at Pulta intake (in September) ...	2·0 (approx.)	6·0 (approx.)	8·0 (approx.)
Water of the Hooghly river at Pulta intake (in April) ...	12·0 (approx.)	8·0 (approx.)	20·0 (approx.)

	Hardness (Parts per 100,000) Temporary.	Permanent.	Total.
Water from the tube well of the Chittagong Municipality ...	3·0	2·0	5·0
Water from the Corporation tube well near Kali's temple, (Kalighat) ...	7·0	19·0	26·0
Water from a tube well at Budge-Budge ...	48·0	140·0	188·0

(*iii*) *Chlorine as chlorides.*—Chlorides, mostly as sodium chloride and occasionally as potassium, calcium and magnesium chlorides, are always present in natural waters. They are derived from the soil; their presence is due also to the influx of sea water (which contains about 3 per cent. of sodium chloride) into the water-bearing stratum, or into rivers and khals as a result of tidal pumping. They give an objectionable taste to water when more than 25 parts of chlorine per 100,000 parts of water are present. Urine contains about 1 per cent. of sodium chloride, and the presence of chlorides in water may also be due to pollution with sewage and urinary matters from stables, byres, etc. The amount of chloride found in a locality far removed from the possibility of pollution may be considered as normal; an increase over the normal may indicate sewage

pollution. The spring water at Darjeeling contains less than 0·5 part of chlorine per 100,000 parts; the tank water uncontaminated with sea water usually contains 1-2 parts; the chlorine-content of river and tube-well waters is, as shown in the following table, very variable:—

Sources of water.	Chlorine (Parts per 100,000).
Water of the Teesta river at Teesta Bridge, Darjeeling	0·5
Water of the Hooghly river at Pulta intake (in September) ...	1·0 (approx.)
Water of the Hooghly river at Pulta intake (in April) ...	4·0 (approx.)
Water of the Meghna at Chandpur ...	1·0
Water of the Meghna at Bhowanigunge, Noakhali District ...	700-800
Water from the tube well of the Chittagong Municipality ...	0·6
Water from the Corporation tube well near Kali's temple, Kalighat ...	3·4
Water from a tube well at Regent Park Estate, Tollygunge ...	7·0
Water from the tube well at Great Eastern Hotel, Calcutta ...	30·0
Water from a tube well in Howrah town	50·0
Water from a tube well at Chandpur	120·0
Water from a tube well at Budge-Budge	over 150·0

(*iv*) *Iron.*—Iron exists in practically all sands, gravels, soils and rocks. In Bengal, the soils in the Madhupur Jungle Tract, in the Barind, and in the western portion of the Burdwan Division are particularly ferruginous.[1] All natural waters derive a certain amount of iron from the soil. Tube-well waters are apt to contain iron in objectionable amounts due to the fact that the water containing considerable amounts of carbonic acid gas acts upon the ferruginous salts which may be present in the soil through which the water passes and also upon the metal pipe, forming soluble ferrous bi-carbonates ; when, however, the water is exposed to the air, the ferrous bi-carbonate dissolved in it is oxidised to the insoluble ferric hydroxide, and the iron is precipitated.

Iron in water has little sanitary significance, for when present in amounts over 0·05 part per 100,000 parts of water, a distinct chalybeate taste precludes its use. Appreciable amounts of iron render water unsuitable for technical purposes ; it stains clothes in the laundry, forms deposits in pipes and cisterns, and is objectionable in tanning and dying. Iron in water supports a fungus—*Grenothrix kuehniana*—which may grow

1 "A Short Geography of Bengal"—By W. H. Arden Wood.

in the pipes in sufficient amounts to obstruct the flow of water or even completely choke the pipe.

(v) *Poisonous metals like lead, copper and zinc.*—Lead may be derived from lead pipes or some other lead objects used in collecting, storing or delivering the water, copper from culinary utensils and zinc from the zinc coating of galvanized iron pipes or cisterns. The amounts of these substances present in water depend principally upon the character of the water and upon the length of time the water is in contact with the metal. As a general rule, the cleanest, softest and best aerated waters are especially prone to act upon lead. A small quantity of copper is dissolved from culinary utensils when water containing sodium chloride, acid, fatty or oily matter is boiled in them. All kinds of water attack zinc in the presence of air, even hard water with an alkaline reaction. The presence of these salts is undesirable in drinking water; probably as little as one-tenth of a grain of lead, one-fifth of a grain of copper and half a grain of zinc per gallon of water are capable of disturbing health.[1]

[1] "Hygiene and Public Health."—By H. R. Kenwood and H. Kerr.

(*vi*) *Sulphates.*—Sulphates of sodium, potassium, calcium and magnesium are usually derived from the soil ; a large proportion of the sulphates is supplied also by the inflow of sea-water. Sulphates in detectable amounts are found often in the water of tidal rivers and occasionally in tube-well waters.

(*vii*) *Organic matter.*—The organic matter in water is of vegetable and animal origin and speedily undergoes changes as a result of fermentation or putrefaction. Carbon is converted into carbon di-oxide, hydrogen into water, sulphur into sulphuretted hydrogen, etc. Nitrogenous organic matters are derived from human urine or from that of other animals, from excrements or from the decay of the protein constituents of dead animals or plants ; they are finally converted into nitrates in three stages by the action of a number of organisms :—

(1) *Ammonisation.*—The proteins are first converted into simpler compounds by organisms of the proteus group. These are further broken up by *B. mycoides*, *B. subtilis*, *B. mesentericus*, and other organisms to produce ammonia. Urea of urine is ammonised by *Micrococcus ureae*. The ammonia is present in the soil as ammonium chloride or ammonium carbonate.

(2) *Nitrosation.*—The ammonium salts are converted into nitrous acid by the nitrite-forming bacterium, Nitrosomonas.

(3) *Nitratation.*—The nitrous acid is converted into nitric acid by the nitrate-forming bacterium, Nitrobacter. Vegetable organic matter forms very little nitric acid, whereas animal organic matter forms a large amount of nitric acid. The acids—nitrous and nitric acids—act upon the calcium, magnesium and sodium compounds in the soil forming nitrites and nitrates. The nitrites have no chance to accumulate because they are readily converted into nitrates.

Although the organic matter speedily undergoes changes, a residuum is left behind in all potable waters; in pure waters it is present in minute traces only. A measure of the amount of organic matter in water is obtained by—

(*a*) "*Oxygen absorbed*" from permanganate (Tidy's process).—This term means the amount of oxygen which the organic matter in water is capable of absorbing from an acidified solution of potassium permanganate when kept at 80°F. for four hours. The presence of nitrite, ferrous salts, sulphides or other unoxidised mineral compounds also causes oxygen to be taken up. "Oxygen

absorbed" is thus an index of the amount of the total oxidisable matter of every kind.

(b) *Free and saline ammonia.*—This is the amount of ammonia obtained by the distillation of water rendered alkaline, if necessary, for the liberation of ammonia from compounds. Free ammonia indicates the presence of putrefying nitrogenous organic matter which has not had time to form the nitrites and nitrates. It may also be formed by the reduction of nitrates and nitrites through the reducing action of ferruginous salts, metal pipes or cisterns, or de-nitrifying organisms.

(c) *Albuminoid nitrogen.*—After the removal of free and saline ammonia as shown above, the water is boiled with alkaline solution of potassium permanganate when a further quantity of ammonia is derived from the breaking up of a portion of the nitrogenous organic matter. The nitrogen equivalent of this ammonia is referred to as albuminoid nitrogen. It is a measure of the undecomposed nitrogenous organic matter contained in the water. It should be noted that different organic substances give different proportions of ammonia on being boiled with alkaline permanganate; hence the value of the numerical result of albuminoid nitrogen depends on the assumption

that the nitrogenous organic matter in the water is uniform in its nature. Nitrogenous organic matter of animal origin yields a much larger amount of ammonia on being boiled with alkaline permanganate solution than a similar amount of vegetable matter; consequently, whether this ammonia has been derived from a small amount of animal matter or a large amount of vegetable matter cannot be stated with certainty from this test.

(*d*) *Nitrites.*—Nitrites represent the transitional stage in the oxidation of nitrogenous organic matter between ammonia and nitrates, and consequently the presence of nitrites in water indicates incomplete oxidation of the protein and therefore at once suggests recent organic pollution. Their absence does not necessarily mean that the water is pure, as the oxidation of organic matter may not have reached this stage or may have just passed it. As has been pointed out previously, nitrites may also be due to the reduction of nitrates through the action of reducing substances or de-nitrifying bacteria.

(*e*) *Nitrates.*—Nitrates are the end products of the oxidation of nitrogenous organic matter. The amount of nitrates in the water depends upon the extent of pollution with nitrogenous

organic matter and on the activity of the nitrifying organisms. The strata supplying the water may also be the source of nitrates. When nitrates are found in water where a certain amount of oxidation is always in progress, they represent partially oxidised nitrogenous organic matter and their amounts must be considered in conjunction with other constituents of the water, particularly free ammonia and albuminoid nitrogen.

The significance of "oxygen absorbed," free and saline ammonia, albuminoid nitrogen, nitrites and nitrates must be judged from joint consideration of all of them as well as of the bacteriological test. A good water does not usually contain nitrite and rarely shows—

more than 0·3 part of "oxygen absorbed" per 100,000 parts of water,
" 0·005 " of free and saline ammonia per 100,000 parts,
" 0·01 " of albuminoid nitrogen per 100,000 parts,
" 0·15 " of nitric nitrogen per 100,000 parts.

Nitrates may be present in much greater amounts in good waters; they are then associated with low free ammonia and albuminoid nitrogen and low "oxygen absorbed," indicating that they have been obtained from a particular water-bearing stratum, or that the oxidation of organic matter has been practically complete and the water was

polluted at some remote period. For instance, the spring water collected in the Rishi Road Reservoir at Kalimpong (Darjeeling District) shows 0·2-0·3 part of nitric nitrogen, 0·0016-0·002 part of free ammonia, 0·006-0·008 part of albuminoid nitrogen, and 0·02-0·04 part of oxygen absorbed per 100,000 parts of water. High nitrates accompanied with marked free ammonia and albuminoid nitrogen indicate that the nitrogenous organic matter has not been completely oxidised and the contamination is recent. It is worthy of note that the organic contaminating matters exist mostly on the surface layers of the soil. The nature of the organic matter occurring in the water of tanks and rivers is therefore dependent upon the nature of the organic pollution of the soil of the collecting area ; the water from these sources is also liable to pollution in various ways as shown on pages 25, 26, 27 and 43, and partial oxidation of organic matter is always in progress. In deep tube wells and springs the waters have percolated a considerable depth of porous strata and have undergone a process of filtration and natural purification ; as a result they are practically free from organic matter. In shallow wells, however, the waters are often insufficiently filtered and the quality of the water.

varies greatly according as whether the surrounding soil is free from organic matters or is charged with them.

Bacteriological Examination.—In the sanitary chemical analysis of a water, we ascertain whether the saline constituents in it are in quality or quantity harmful or unobjectionable, and determine the amounts of free and saline ammonia, albuminoid nitrogen, nitrites, nitrates, etc., indicative of the presence of organic matter (sewage, etc.). It is only the past history and not present conditions which the chemical analysis reveals. The bacteriological examination is of far greater delicacy in the detection of sewage pollution than the chemical analysis and gives a correct picture of the hygienic condition of the water at the moment of examination. The bacteriological examination of a sample of water is undertaken to determine the number of bacteria (in a given amount of water) which will grow under definite conditions of the test, to ascertain the presence or absence of bacteria (in a given quantity of water) indicating excremental pollution, and to find out whether the water contains any pathogenic organism.

In the standard test for the "total count," a tube of nutrient agar medium is melted and then cooled to about 40°C. and seeded with 1 c.c. or

0·1 c.c. of the water to be examined ; the mixture is then poured out in a Petri dish and allowed to set for a few minutes after which it is incubated for 24 hours at 37°C. to permit a reproduction of each of the bacteria in the water and the formation of visible colonies which may be counted. Roughly speaking, the number of bacteria in the water corresponds to the amount of organic pollution which forms a suitable pabulum for them. Surface waters (that is, the waters of tanks, lakes, rivers and khals) contain the greatest number of bacteria on account of the exposure to contamination to which they are liable. The river water in particular frequently shows countless colonies (*i.e.* over 5,000) per c.c. The waters of deep tube wells and springs are often found to be practically sterile, as the filtering action of the earth removes most of the bacteria as well as their food materials. In shallow wells, however, there is the possibility of the contamination with surface water which has little chance of being purified in its passage through the soil ; the bacterial content of the shallow well water is therefore dependent upon the surroundings. It is generally stated that a good water should not show over 100 colonies per c.c. It should be noted, however, that a number of bacteria, called saprophytes, may be normally present in water and

are capable of multiplying under certain conditions. Consequently, although a paucity of micro-organisms might indicate a condition of purity, it does not necessarily follow that a large number of them point to contamination.

The main object of the bacteriological examination of water is to measure the degree of excremental pollution to which the water has been subjected. Organisms of the *Bact. Coli* group are normal inhabitants of the intestinal tract of men and many other animals, and occur regularly in their excreta. The germs of cholera, dysentery, typhoid fever and some other diseases accompany the organisms of the *Bact. Coli* group in the faeces of people who are actually suffering from these diseases or are in the "carrier" stage. Organisms of the *Bact. Aerogenes* group also may be found in small numbers in faecal matter. The presence of organisms of the *Coli-aerogenes* group (which are capable of producing acid and gas in MacConkey's neutral red bile-salt lactose-peptone broth and of growing aerobically on agar media containing 0·5 per cent. bile salt) in water supplies is therefore regarded as direct evidence of excremental contamination. These organisms are not harmful in themselves but they point indirectly to the possibility of the accompanying

presence of microbes of definitely pathogenic sort. When they are absent from a water or when they are present in large amounts of water, we may infer that the water is of great purity. The spring water at Darjeeling and the deep tube-well waters in Bengal frequently do not show any organism of the *Coli-aerogenes* group in 60 c.c. of water and are thus extremely pure bacteriologically. The river water may show these organisms in 0·01 c.c. or even in 0·001 c.c., indicating a large amount of excremental contamination. Generally speaking, a potable water should not usually contain any organism of the *Coli-aerogenes* group in at least 10 c.c.

Bacteriologists are called upon to search for pathogenic bacteria in a water only when it is suspected of causing diseases.

Microscopical Examination.—Microscopical examination of a sample of clear water reveals little or nothing to the observer. In turbid waters, however, many mineral, vegetable and animal substances may be present in suspension. It is necessary to collect the sediment or deposit which falls to the bottom of the vessel in which the turbid water stands, and the sediment is examined microscopically to determine the nature of suspended matters with a view to ascertaining the cause of

turbidity, odour, and taste, elucidating the result of chemical examination, and detecting sewage contamination. The sediment may consist of mineral matter (*e.g.* sand, clay, etc.), lifeless vegetable and animal matters (such as vegetable debris in the shape of dotted ducts, spiral vessels, parenchymatous cells, bits of cuticle with the hair still adhering, the down of seeds, etc., hairs, feathers, textile fibres, scales, wings and legs of insects, etc., and the various substances found in the faeces such as muscle fibres, starch cells, shreds of mucous membrane, epithelial cells, etc.), and living vegetable and animal organisms. Besides the ubiquitous bacteria, the most common tiny living organisms of the vegetable kingdom include the following :—*Beggiatoa alba*, Crenothrix, Cladothrix and a wide variety of algae such as the different species of Desmids, Oscillatoria, Diatoms, etc. The algae are found both in water, particularly in tank water, and in filter beds. When present in great abundance, they may furnish a dark and repulsive appearance, and offensive taste and smell are produced by their death and decay. " The blue-green alga *Clathrocystis aeruginosa* is the most dominant species found all over India in tanks, pools, etc., floating in great abundance

as minute blue-green granules."[1] Amongst the microscopic living animals occurring in natural waters are certain of the Protozoa (*e.g.*, Amoeba, Paramoecium, Vorticella, etc.), Polyzoa and Rotifers; the crustaceans, water fleas, insect larvae and some "worms" parasitic in man are, however, visible without magnification.

Sanitary Survey.—The sanitary survey of a source of water is necessary to get information as to the risks of pollution to which it has been subjected. The laboratory analysis and the field survey are, in fact, complementary. A surface water may on the date of examination be exceptionally free from organic impurities but subsequently it may contain the germs of cholera, typhoid fever and other water-borne diseases, and these germs may come from sources that would at once be perfectly evident from a sanitary survey of the watershed. On the other hand, the sanitary survey may indicate nothing suspicious and yet the laboratory analysis of the water may reveal the presence of sewage. If house or barn-yard drainage or sewage is actually seen to enter a water used for drinking purposes, it is obviously

[1] "The Role of Aquatic Vegetation in Indian Waters"—By K. Biswas, Sir P. C. Ray Commemoration Volume, 1933.

unnecessary to carry out the delicate chemical or bacteriological tests to detect pollution.

Clinical result.—The water we drink has come in contact with the earth and many other substances, dissolving many organic and inorganic impurities. Many of these impurities are not detected in the laboratory by the routine methods used and may be detrimental to health. The water supply may also be deficient in some essential constituent such as iodine, the lack of which in our food and drink may lead to goitre. The clinical result is therefore the final test for approving or rejecting a water which is to be used as a source of supply.

CHAPTER X

Relation of Water Supplies to Diseases

Water is occasionally responsible for diseases like dyspepsia and diarrhoea due to the presence of mineral and organic impurities; it may carry metallic poisons such as salts of lead, etc.; it may contain qualities which bring about derangements of metabolism resulting in such conditions as goitre; and it may be a vehicle for certain infectious diseases.

(1) *Dyspepsia and diarrhoea.*—(*i*) Particles of suspended clay, mica or vegetable matter have irritating effects upon the gastro-intestinal tract, producing diarrhoea.

(*ii*) It is commonly stated that a water containing more than 50 parts of dissolved solids per 100,000 parts is unfit for drinking purposes. Habitual consumers of a water containing 9 or 10 parts of dissolved solids per 100,000 parts might suffer from gastro-intestinal effects on account of the consumption of water containing more than 50 parts of dissolved solids per 100,000 parts; on the other hand, thousands of mill coolies at Budge-Budge use deep tube-well water containing over

400 parts of dissolved solids per 100,000 parts and they apparently suffer no inconvenience from its consumption.

(*iii*) Excessive permanent hardness, particularly that caused by magnesium sulphate or other magnesium salts, sometimes causes diarrhoea amongst those who are not used to them. It is important to note that an abrupt change from a soft to a hard water, or *vice versa,* may lead to gastro-intestinal disturbances which are temporary in effect.

(*iv*) Diarrhoea and dyspepsia are also produced by the consumption of brackish waters, the injurious salts being especially the sulphates of magnesium, calcium and sodium and the chloride of magnesium.

(*v*) Excessive amounts of vegetable organic matter may give rise to diarrhoea and other bowel complaints.

Organic matter of animal origin soon putrefies and some of the intermediate products of putrefaction (such as ptomaines, etc.), may have toxic properties. Consequently, a water contaminated with animal organic matter cannot be regarded as safe for human consumption even though freed from bacteria by filtration or sterilisation, until and unless it (*i.e.*, the animal

organic matter) has been converted into innocuous substances by natural purification. Sewage-polluted waters produce diarrhoea due to the degradation products of protein decomposition or to bacterial action or to bacterial toxins; they may also be the cause of specific infectious diseases such as cholera, typhoid fever, dysentery, etc.

(2) *Metallic poisons (e.g., salts of lead, copper, zinc, iron, etc.).*—Lead and copper are cumulative poisons and are objectionable in potable waters. Zinc also is not a desirable constituent of potable waters; the water containing it may cause obstinate constipation, especially in children. "Iron in general water supply should not exceed $\frac{1}{4}$ to $\frac{1}{2}$ grain per gallon, as excess of this quantity may, after a time, provoke dyspepsia and headache in some people."

(3) *Goitre.*—Goitre is generally taken to mean specifically an enlargement of the neck caused by the swelling of the thyroid glands there situated. Thyroxin is the most important of the substances present in the thyroid secretion and contains about 65 per cent. of iodine, and iodine is necessary for its formation. A sufficient quantity of iodine must therefore be supplied to the body in the daily food and drink that it receives. When, however, the supply of iodine falls short the gland

cannot function properly, and in an attempt to make good the deficiency, it seems to feel that if it were larger, it would be more efficient. It therefore increases in size, giving rise to the characteristic swelling of the neck known as goitre.

As regards the source of iodine, it may be pointed out that the sea is the world's greatest iodine reservoir. The nearer we get to the sea and the further from the tops of drainage areas, the greater is the iodine content of the plant and animal food and of the water that we consume and consequently the less is the incidence of goitre. McCarrison holds further that even when the iodine intake is sufficient, the iodine absorption from the gut may be interfered with by bacterial action. Continued ingestion of such bacteria in polluted water supplies might cause goitre.[1] There are therefore two practical ways of attacking the goitre problem so far as the relation of water supplies to it is concerned. Firstly, the water supply deficient in iodine must be iodised; this method is used in Rochester, U.S.A. Secondly, the water supply must be bacteriologically pure. In India goitre is most common in districts which

[1] 'Indian Medical Year, 1925' edited by R. Knowles.

lie immediately south of the Himalayas and in the hilly regions of Assam and Burma. In Bengal it is common in the districts of Darjeeling and Jalpaiguri; in other parts of the province it is rare or uncommon.[1]

(4) *Infectious diseases.*—Water-borne infectious diseases may be divided into three groups, namely, bacterial diseases, protozoal diseases, and helminthic diseases.

Cholera is by far the most dreaded of water-borne bacterial diseases in Bengal. It is, in fact, believed to be mainly a water-borne disease in this province. The other chief water-borne bacterial diseases are typhoid and paratyphoid fevers and bacillary dysentery. The specific bacilli are contained in the faeces of actual sufferers or of "carriers," and the diseases are contracted by the ingestion of these bacilli with water polluted with specifically infected faeces.

Of all the intestinal protozoa of man, *Entamoeba histolytica* is the most dangerous as it is the cause of amoebic dysentery and liver abscess. Infection is acquired by swallowing the cysts contained in the excreta of convalescents and

The Geographical Distribution o some of the Diseases of India, By J. W. D. Megaw and J. C. Gupta, Indian Medical Gazette, June, 1927.

carriers. When swallowed, the contents of the cyst divide into small amoebae which escape into the intestine by solution of the cyst wall. The water may become infected by the excreta of a cyst-carrier, or the cysts of *Entamoeba histolytica* may be washed from dried stool into a water supply.

The chief water-borne helminthic diseases are the following:—

(*i*) Diseases caused by the Nematodes such as *Oxyuris vermicularis* (thread worm), *Ascaris lumbricoides* (round worm), *Trichocephalus dispar* (whip worm), *Ancylostoma duodenale* (hook worm), and *Dracunculus medinensis* (guinea worm). A person suffering from any of these diseases passes large numbers of eggs of the particular parasite in the faeces which may contaminate the water supply, and the eggs, larvae or other stages in the life-cycle of the parasite may enter the body along with the contaminated water. In the case of guinea worm, the larvae swim about in the water, undergo a certain degree of development in small fresh water crustacea (cyclops), and reach man as he inadvertently swallows a cyclops containing guinea-worm larvae. Guinea worm infection is unknown in Bengal

but common in Madras, Bombay and North-West Provinces.[1]

(*ii*) Schistosomiasis or Bilharziasis is the disease caused by the Trematode, *Schistosoma* (*Bilharzia*) *haematobium*. The disease is characteristically African, Egypt being the most notorious area. The worms which infect a fresh subject originate from the eggs which have left the preceding host with the faeces or urine. The eggs hatch in water and give rise to tiny larvae which are capable of further development by entering the body of certain kinds of pond snails. After a succession of stages in the snails, free-swimming forms result which leave the molluscs and swim about in the water. These free-swimming schistosome cercariae can actually force their way through the skin of a human being. One sees clearly how the infection can occur whilst puddling in water and bathing, and drinking infected water would naturally be equally dangerous.

From what has been described above regarding the water-borne infectious diseases, it will be recognised that the real source of danger to

[1] The Geographical Distribution of some of the Diseases of India, by J. W. D. Megaw and J. C. Gupta, Indian Medical Gazette, June, 1927.

health is the introduction of infected human faeces into potable water. The contamination of water with human faeces may be infinitely small in volume, yet almost inconceivably dangerous owing to its specific taint. When we consider the insanitary habits of the people in rural areas and the promiscuous defaecation leading to the contamination of soils and water supplies, we can easily realise how great is the risk of contracting these diseases. A sound axiom is therefore to look upon all human faeces as potentially infective and to purify the water subjected to human faecal pollution.

CHAPTER XI

Purification of Water

The terms "pure" and "impure," as applied to water, are merely relative. All natural waters are more or less impure as they contain various substances—solid, liquid or gaseous—taken up from the air or from the soil or from both. When the term "pure" is applied to a potable water we simply mean that it does not contain any substance which either from its quantity or quality is likely to endanger the health of the consumer. The chief desiderata of a potable water are: (1) freedom from turbidity, colour and odour, (2) a high degree of purity with reference to all organic matter including disease-germs, (3) the presence of a few grains per gallon of mineral salts derived naturally from the earth's crust over which the water flows or through which it percolates, and (4) freedom from lead, copper, or other objectionable metallic salts. What should be aimed at is to procure a supply of water sufficiently good to require no artificial

purification. The majority of our water supplies are, however, unsuitable in their natural condition for drinking purposes and should be efficiently purified before it reaches the consumer. The methods commonly employed for purification are :—

(*a*) Storage and sedimentation.
(*b*) Filtration.
(*c*) Sterilisation.
(*d*) Softening of hard waters.
(*e*) Elimination of iron, lead, etc.
(*f*) Removal of colour, odour and taste.
(*g*) Destruction of algal growths.
(*h*) Distillation.

One or more of these processes are usually adopted in the treatment of water for human consumption.

Storage and Sedimentation.

These are the simplest means of improving the sanitary quality of a water. When the water is stored in reservoirs, the settleable matters are subject to sedimentation, the organic matter is largely oxi-dised, the colour is gradually bleached and a notable

reduction in the number of bacteria occurs due chiefly to subsidence, germicidal effect of direct sunlight, lack of food supply and unfavourable environment. The efficiency of all the purifying agencies will increase with the prolongation of the period for which they act. Any water which has been stored for four weeks is practically safe bacteriologically.

The clarification of turbid waters is hastened by the addition of potash alum, aluminium sulphate, alumino-ferric (a commercial form of aluminium sulphate containing a large amount of iron), or other coagulants. When potash alum or aluminium sulphate is added to water, it reacts with the alkaline carbonates forming aluminium hydroxide; the reactions are as follows:—

$$\underset{948}{\underset{\text{(Potash alum)}}{K_2SO_4, Al_2(SO_4)_3, 24\ H_2O}} + \underset{300}{3\ CaCO_3}$$

$$= K_2SO_4 + 3\ CaSO_4 + Al_2(OH)_6 + 3\ CO_2 + 21\ H_2O \quad (1)$$

$$\underset{666}{\underset{\text{(Aluminium sulphate)}}{Al_2(SO_4)_3, 18\ H_2O}} + \underset{300}{3\ CaCO_3}$$

$$= 3\ CaSO_4 + Al_2(OH)_6 + 3\ CO_2 + 15\ H_2O \quad \ldots\ (2)$$

In water, however, the reaction is with the bicarbonates of calcium and magnesium :—

$$Al_2(SO_4)_3, 18H_2O + 3\,Ca(HCO_3)_2 = 3CaSO_4 + Al_2(OH)_6 + 6\,CO_2 + 18\,H_2O \quad \ldots (3)$$

Calcium bicarbonate is thus converted into calcium sulphate; similarly, magnesium bicarbonate is converted into magnesium sulphate. The aluminium hydroxide is thrown out of solution as a flocculent precipitate which entangles much of the suspended matter and bacteria and carries them down on settling, and the water becomes clear. The quantity of the coagulating reagent required for clarification varies with the turbidity and other factors. The actual amount to be used is ordinarily determined by small-scale trials, for if enough of it is not added, the result is incomplete, and if too much is used, it remains in the water as such. From the above equations (1 and 2), it will be seen that 300 parts by weight of calcium carbonate are required to deal with 948 parts by weight of potash alum or 666 parts by weight of aluminium sulphate ; in other words, 0·7 grain per gallon of alkalinity (or 1·0 part of alkalinity per 100,000 parts of water) expressed as calcium carbonate does not require more than

2·2 grains of potash alum or 1·6 grains of aluminium sulphate per gallon for complete precipitation. If the water is deficient in alkalinity or is acid, lime or sodium carbonate must be added in a definite quantity, dependent on the deficiency and the amount of the coagulant (alum, etc.) added. The treated water should be decanted or drawn off immediately after the sedimentation is complete. It should be noted that the percentage removal of bacteria by the use of coagulants alone is too low to be safe from a hygienic standpoint.

Filtration.

Filtration of water on a large scale, as in municipal waterworks, is effected either in slow-sand filters or in rapid-sand or mechanical filters.

Slow-sand filters.—The turbid waters drawn from rivers is first stored in a reservoir (so that as much of settleable matter as possible may be deposited by sedimentation) for the reason that this prevents undue choking or clogging of the surface of the filters and thus effects a great economy. During the rainy season, natural subsidence may fail to remove the turbidity satisfactorily, and clarification is assisted by the

use of a coagulant. From the storage reservoir the clarified water is conducted to the surface of the filter bed consisting of a watertight reservoir which contains stratified filtering material of various degrees of fineness, and is suitably under-drained. A layer of broken stone about 6 inches thick is first laid on the bottom over the collecting drains, and over this are successive layers of coarse gravel, fine gravel, coarse sand and fine sand, the thickness of the last layer of fine sand varying from 1 to 4 feet. The depth of the water over the surface of the filter is about 3 feet. As the water passes slowly through such a filter from above downwards, a superficial gelatinous deposit (called the schmutzdecke) consisting of algae, bacteria and other micro-organisms is formed on the surface of the sand layer. This schmutzdecke effectively holds back most of the micro-organisms, and until it has been formed, the filter has no purifying action. Continual passage of the water through the filter increases the thickness of the gelatinous coating and in time the filter becomes clogged. Periodical cleaning involving the scraping of the schmutzdecke together with the surface layer of sand about an inch in thickness is therefore necessary. The depth of the sand

layer is reduced by successive scrapings until it approaches 12 inches, when fresh sand is added. Slow-sand filters are usually worked at a rate of about 2½ million gallons per acre per day (that is, about 2½ gallons per square foot per hour). An extensive tract of land is consequently required for a slow-sand filter. In efficiently filtered water it is possible to eliminate over 99 per cent. of the bacteria. The filter beds not only intercept bacteria but also purify the water physically and chemically; the particles in suspension are strained out and oxidation and nitrification of organic matter take place. When the filter is not well managed, the required standard of purity of the filtered water cannot be maintained and the filter may be actively dangerous by engendering a false sense of security. It must be emphasized that even the removal of 99 per cent. of the bacteria in the water supply may be insufficient to assure safety; for instance, if the water before filtration contains per c.c. 100,000 bacteria of which at least 1,000 are of the coli-aerogenes group, the removal of 99 per cent. of the bacteria will leave 1,000 bacteria (of which at least 10 are of the coli-aerogenes group) per c.c. in the effluent which are too many. Consequently, the filtered water should not be used until the

bacteriological examination shows that it has become safe. The water may however be further purified by chlorination or some other method of sterilisation to remove completely the possibility of the survival of harmful micro-organisms.

After purification, the water requires protection from pollution before it reaches the consumer. In towns the filtered water is distributed through cast iron pipes laid underground in the streets. House to house distribution from the street mains is generally effected by galvanised iron pipes. These water pipes should be watertight in order to prevent the inward diffusion of polluted drainage, etc., from the land traversed. It sometimes happens that the filtered water pipes leak in their joints. These leaky water pipes may run close to filthy surface drains or through ground reeking with sewage ; they may also pass through gully-pits and through sewers and manholes with the leaky joints within the gully-pits, sewers or manholes; there may also be cross-connections between leaking water and sewage pipes with the result that the sewage, which has leaked out from the sewer pipe, collects round the filtered water pipe. If there is a constant water supply, the water pipes are kept constantly charged with water under pressure, and as the movement of water is outwards, the leaky

water pipes will not suck in the filth. In many places, however, the water is supplied on the intermittent system, and when the flow of water in the mains is stopped for a part of every day, a partial vacuum is liable to be created inside the water pipes due to gradual leakage at defective joints and in consequence the filth will be sucked into the water-pipe and thus the water will be contaminated during its transit from the filtered water reservoir to the consumer. Hence, the leaks in the water pipes must be detected and dealt with as early as possible, cross-connections between water and sewage pipes must be avoided; the filtered water pipes must not be made to pass through gully-pits, sewers or manholes, and the joints must be placed as far away as possible from the filthy drains, gully-pits, sewers and manholes.

Rapid-sand filters or mechanical filters.—The mechanical filter operates either by gravity or under pressure. It is usually of ferro-concrete construction, square or rectangular in shape, containing a system of under-drains placed on its bottom. The layers of gravel over the collecting drains are graded in size from $\frac{3}{4}$ inch to $2\frac{1}{2}$ inches and approximately 18 inches in depth. A layer of selected sand or crushed quartz about 3 feet

thick is placed over the gravel. The water is first treated with a coagulant (such as aluminium sulphate) in a coagulating basin. The bicarbonates of calcium and magnesium react with the aluminium sulphate to form aluminium hydroxide which is thrown out of the solution as a flocculent precipitate. If the bi-carbonates of calcium and magnesium are not normally present in the water, some lime or sodium carbonate must be added to produce the precipitate of aluminium hydroxide. The water is next passed rapidly through the sand layer, the "head" of water ranging from 1 to 10 feet. The aluminium hydroxide together with the suspended matter in the water is deposited on the surface of sand forming the artificial schmutzdecke instead of the natural schmutzdecke of the slow-sand filter bed. As the filtration proceeds, the deposit becomes thicker and thicker and when it becomes very thick so as to clog the filter, the filter is washed by reversing the flow of water and mechanically agitating the sand. The average rate of filtration through a rapid-sand filter is 150 million gallons per acre per day which is closely equivalent to 2½ gallons per square foot per minute. As the filters operate at about sixty times the speed of the slow-sand filter, only one-sixtieth of the area purifies an equal volume of

water. Consequently, the cost of construction of the filter is much reduced. The process is mainly a mechanical straining and is a comparatively cheap method of supplying a clean-looking water from a turbid source. The dissolved colouring matter (the reduction of which is slightly effected by the slow-sand filtration) is also removed. The bacterial purification, however, is not as constant and uniformly high as that obtained by slow-sand filtration. Mechanical filtration is therefore invariably followed by sterilisation. The cost of sterilisation following rapid filtration would be considerably less than the cost of slow-sand filtration.

In the household, the best way of dealing promptly and safely with drinking water is to remove the suspended matter and then sterilise it by boiling or chlorination. The simplest and cheapest domestic filter consists of four earthenware vessels arranged one over the other in a wooden frame. The first vessel is filled with the water after preliminary clarification. The water flows into the second vessel containing wood charcoal which is useful in removing colour and odour in particular. From the second vessel the water passes into the third one where there is a layer of fin e sand over a layer of gravel. Ultimately,

the filtered water drops into the remaining vessel. This water if sterilised by boiling, chlorination, etc., before using, becomes safe bacteriologically. The filters are to be periodically cleansed and the filtering medium renewed; otherwise, the pores of the filtering medium become clogged with putrescible organic matters which form a suitable nidus for the growth and development of living organisms which further contaminate the water in place of purifying it.

The other common forms of domestic filters are the Pasteur-Chamberland filter made of unglazed porcelain and Berkefeld filter made of diatomaceous earth called kiesselguhr; the latter is more porous and therefore less satisfactory from the point of view of retaining bacteria than the former. The Pasteur-Chamberland filters are especially serviceable in rendering the turbid water clear. They require periodical cleaning every few days by a hard brush to remove the slimy deposits on the surface of the porcelain; if this is not done, the delivery of water becomes very much reduced, and separated organisms may in time grow through the filter. In the laboratory it is possible by the use of special precautions to pass water through a Pasteur-Chamberland filter so as to obtain a sterile filtrate. This requires

skilled bacteriological manipulation of a kind that cannot be obtained in the ordinary household; so the water filtered through such a filter should be sterilised before consumption.

Sterilisation.

Water is sterilised to kill bacteria causing water-borne diseases. Sterilisation of water is a very cheap insurance against water-borne infectious diseases. Three different methods of sterilisation have been employed:—heat, chemical sterilising agents and ultra-violet rays.

(1) *Sterilisation of water by heat.*—In the household, the boiling of water for 5 minutes is an efficient means of destroying the non-spore-bearing organisms such as the germs of cholera, typhoid fever, dysentery, etc. Boiled water acquires a flat taste owing to the escape of dissolved gases and should be aerated before being used for drinking. It has frequently a burnt flavour due to changes in the organic matter which take place at 100°C. When large quantities of water have to be regularly sterilised by boiling, the expense is prohibitive.

(2) *Sterilisation of water by chemicals*—

(i) *Chlorination.*—Of all the processes of sterilisation, chlorination by the addition of

chlorine gas (readily obtained from cylinders of liquid chlorine), bleaching powder or sodium hypochlorite solution has continued to advance most rapidly. In large installations, liquid chlorine is now used almost universally. When chlorine is added to water, equivalent amounts of hypochlorous and hydrochloric acids are formed according to the equation—

$$Cl_2 + H_2O \rightleftharpoons HOCl + HCl$$

The reaction is reversible, but goes almost completely to the right in very dilute solutions. The hypochlorous acid so formed rapidly breaks down to nascent oxygen and hydrochloric acid.

$$HOCl = HCl + O$$

The hydrochloric acid combines with the bicarbonates of calcium and magnesium dissolved in the water. If there is an excess of hydrochloric acid, it reacts with the hypochlorous acid with the liberation of free chlorine—

$$HCl + HOCl \rightleftharpoons Cl_2 + H_2O$$

The exact cause of the lethal powers of chlorine is not known with certainty. At one time it was thought that the bactericidal action of

chlorine was purely an oxidation process due to the evolution of nascent oxygen ; later views, however, incline to the opinion that chlorine exerts a direct toxic action.

The principal and essential constituent of bleaching powder is calcium chloro-hypochlorite, Ca(OCl)Cl. By the term "available chlorine" in bleaching powder is meant the amount of chlorine which is present as calcium chloro-hypochlorite and liberated by the action of dilute acid ; *e.g.*,

$$Ca(OCl)Cl + 2\,HCl = CaCl_2 + H_2O + Cl_2$$

When water is added to bleaching powder, calcium chloro-hypochlorite is decomposed into calcium chloride and calcium hypochlorite:

$$2\,Ca(OCl)Cl = CaCl_2 + Ca(OCl)_2$$

Calcium hypochlorite then reacts with the carbonic acid gas naturally present in the water producing hypochlorous acid and calcium carbonate:

$$Ca(OCl)_2 + H_2O + CO_2 = 2HOCl + CaCO_3$$

The hypochlorous acid next breaks down to nascent oxygen and hydrochloric acid:

$$2\,HOCl = 2\,O + 2\,HCl$$

Hypochlorous acid is also decomposed by hydrochloric acid with the evolution of chlorine:

$$HOCl + HCl \rightleftharpoons Cl_2 + H_2O$$

Usually, the amount of chlorine which is chemically equivalent to the nascent oxygen furnished by the calcium chloro-hypochlorite is returned as the available chlorine: 2 O˙(32) = $2Cl_2$(142). The amount of available chlorine contained in bleaching powder seldom exceeds 35 per cent. which is the equivalent of about 7·9 per cent. of the nascent oxygen.

The action of a solution of sodium hypochlorite in water is just like the action of the calcium hypochlorite.

The amount of chlorine required to effect complete sterilisation depends upon many factors, the chief of which are the amount of oxidisable matter present in the water and the time of contact allowed after the addition of chlorine. The more organic matter the water contains, the more chlorine is necessary, since some chlorine is used up in the oxidation of organic matter, and bactericidal action will usually not take place until the oxidation of organic matter is completed. It is therefore necessary to submit the water

to some preliminary treatment so as to purify it partially in order that the wastage of chlorine may be avoided. Like most chemical reactions, time is required for chlorine to effect complete sterilisation. It should be noted that sterilisation by means of chlorine is quicker in acid than in alkaline solution ; for instance, with 0·2 part per million of residual chlorine, it was found :

at $p^H = 6{\cdot}0$, *B. Coli* of the type used in the test were killed in 5 minutes ;

at $p^H = 7{\cdot}0$, 1 per cent of the *B. Coli* survived after thirty minutes' contact ;

at $p^H = 8{\cdot}0$, 44 per cent. of the *B. Coli* survived after thirty minutes' contact.

By increasing the dose, the time of contact can however be considerably reduced. It is therefore necessary in every case to determine, by small-scale experiments, what dose of chlorine is required for the particular water. In the case of any potable water it is rarely necessary to add more than one part of available chlorine per million parts of water so as to render it quite safe after half an hour's contact.

This proportion of one part of chlorine per million parts of water is obtained by adding to 1,000,000 lbs. or 100,000 gallons of water, 1 lb. of liquid chlorine, 3 lbs. of bleaching powder containing 33 per cent. of available chlorine, or 50 lbs. of sodium hypochlorite containing 2 per cent. of available chlorine.

The most serious disadvantage in the use of chlorine for the sterilisation of water is the danger of producing an unpleasant taste. When a very small dose of chlorine is added, no taste is produced but the water is not sterilised; when more chlorine is added, the water is sterilised but an "iodoform" taste may develop which is attributed to chlorophenol bodies produced by the action of chlorine on the phenolic substances which are derived from industrial wastes from the carbonisation of coal, washings from tarred roads, extracts of leaves of various plants, etc.; if a larger amount of chlorine than that required for sterilisation is added, the iodoform taste is destroyed, but the water acquires a chlorinous taste. Hence the bold course, though the more expensive, is to superchlorinate the water and then to dechlorinate it. Sulphur di-oxide and "activated carbon" are the most widely used dechlorinating agents. The effect of adding sulphur di-oxide to water

containing free chlorine takes place according to the following reaction:

$$Cl_2 + SO_2 + 2H_2O = 2HCl + H_2SO_4$$

The dechlorinating action of the carbon is said to be the result of the following reaction:

$$2Cl_2 + C + 2H_2O = 4HCl + CO_2$$

The hydrochloric acid formed is neutralised by the carbonates present in the water, or in special cases calcium carbonate may be mixed with the activated carbon for this purpose. The carbon needs regeneration and revivification at intervals and this is usually carried out by treatment with warm sodium carbonate solution. It should be noted that if the chlorinated water is stored for 24 hours or even less and kept warmed, the excess of chlorine will be absorbed and dechlorination may not be necessary.

During the last few years much attention has been given to the use of ammonia in conjunction with chlorine to prevent the development of the iodoform taste. This method is now almost universally adopted for the sterilisation of water which contains traces of impurities producing the iodoform taste on the addition of chlorine alone.

The water is treated first with ammonia gas or with ammonium sulphate to prevent the formation of chlorophenol compounds and then with the required amount of chlorine. Arrangement should be made to guarantee a contact period of at least two hours between the chlorination of water and its consumption. Ammonia and chlorine react in the following manner:

(1) When p^H is over 8·4,

$$\begin{array}{cccc} NH_3 + & Cl_2 = & NH_2Cl & + \; HCl \\ & & \text{(mono-chloramine)} & \\ 17 & 71 & 51·5 & 36·5 \end{array}$$

The ratio between ammonia and chlorine is roughly 1: 4.

(2) When p^H is 4·4 to 5·5, and there is an excess of chlorine, di-chloramine is formed:

$$\begin{array}{cccc} NH_3 + & 2Cl_2 = & NHCl_2 & + \; 2HCl \\ & & \text{(di-chloramine)} & \\ 17 & 142 & 86 & 73 \end{array}$$

The ratio between ammonia and chlorine is roughly 1: 8.

(3) When p^H is 5·5 to 8·4, both mono- and di-chloramines exist.

The dose of ammonia must therefore be found experimentally. The ammonia-chlorine method has the following advantages:—

(*a*) Dilute chloramine (formed by the addition of chlorine to a dilute solution of ammonia) solutions are weak oxidising agents and consequently, unlike chlorine alone, there is no deviation by the oxidation of organic impurities.

(*b*) Chloramines are much better germicides than chlorine alone.

(*c*) Chloramines are without taste or smell at the dilutions commonly used and are more stable than chlorine alone and consequently retain their germicidal power over much longer periods.

(*d*) Chloramines are the best known defence against larvæ or eggs of human parasites and of microscopic disease carriers, *e.g.*, cyclops, mosquito larvæ, etc.

(ii) *Excess-liming.*—When lime is added to water, it unites with the carbonic acid gas and the bi-carbonates of calcium and magnesium, forming the carbonates of calcium and magnesium which are thrown out of the solution, and the water is softened. When an excess of good quicklime

(about 2 grains per gallon beyond that necessary to precipitate the calcium and magnesium salts) is added to water, it exercises a strong bactericidal action. The excess of lime is afterwards removed by treating the limed water with a sufficiency of hard water which has been stored for some time so as to have become largely purified. The excess lime method has also the advantage of precipitating much of the organic matter. Its chief attraction lies in the harmlessness of the chemical used and the absence of taste. This method alone has not been extensively practised. In the case of hard waters, so much lime is required to overcome the hardness that its use is not economical unless softening is necessary at the same time.

(*iii*) *Permanganation.*—Potassium permanganate ($2\,KMnO_4 = K_2O,\ 2\,MnO,\ 5\,O$) is a powerful oxidizing agent and a germicide. It first oxidizes the organic matter and then attacks the bacteria. The amount of permanganate necessary for the purification of a water depends, therefore, upon the amount of organic impurities in the water. A sufficient amount of the chemical (about half a grain per gallon) is to be added to the water to produce a faint pink tinge lasting several hours. The treated water should be allowed to stand

until the pink tinge disappears and subsequently filtered so as to remove the precipitate of manganous oxide which is formed. The usefulness of potassium permanganate is however limited by the facts that it has a comparatively low efficiency in destroying bacteria and that it is relatively expensive.

(iv) Ozonization.—The molecule of ozone readily gives up one atom of it in a nascent condition ($O_3 = O + O_2$). It is therefore a very powerful oxidizing agent and germicide. Its use has the great advantage that no extraneous chemical is added to the water, ozone simply becoming oxygen. Usually a very small amount of ozone (1 to 3 milligrams per litre of water) is brought into intimate contact with all portions of the water to be treated so as to sterilise it. The quantity of ozone required for the sterilisation of water is, however, dependent upon the amount of organic impurities contained in it, for much of the ozone is used up by the organic impurities before it acts upon the micro-organisms. It is necessary first to clarify the water by some method before applying the ozone. The ozonizing process is applied on a large scale in a number of places in America and Europe, particularly in France. But the electrical installation for the generation of ozone in

quantities sufficient to sterilise large volumes of water is both expensive and complicated. Where water power is available and the cost of electrical energy is reasonably cheap, it would appear that this method of sterilisation may have its advantages, especially where the obtaining of chlorine is a difficulty because of lack of accessibility.

(3) *Sterilisation of water by ultra-violet rays.*—Ultra-violet rays are actively bactericidal. Sterilisation of water by ultra-violet rays is really an accelerated form of the natural purification effected by sunlight, the bactericidal action of which is due to the ultra-violet rays. A very large proportion of the ultra-violet rays of sunlight is however absorbed by the envelope of the air. Hence, any process or apparatus which can apply to the water a light richer in these rays will induce a more rapid bactericidal action. The light given from a mercury arc vapour lamp enclosed in a tube of transparent quartz is particularly rich in ultra-violet rays and it has been pressed into service for sterilising water. In the ultra-violet ray treatment, the necessary conditions are that the water must be clear and bright (turbidity of the water or the presence of colloidal matter seriously interfering with the action of the rays), that the thickness of the film of water

penetrated by the light must be slight, and that the water must be violently agitated, and under such conditions it is sterilised by exposure to these rays for a short time (30 to 60 seconds). This method of sterilisation has the advantage that the water is not changed chemically, and it may be adopted for private water supplies, as for office buildings, institutions, and particularly for swimming pools. In several cities in France and elsewhere, the municipal water supply is treated by this process. The simplicity of the apparatus and its comparative cheapness make it attractive, so that it doubtless will receive much attention in the future.

Softening of Hard Waters.

Softening (*i.e.*, the removal of calcium and magnesium salts from hard waters) is effected by two important processes—the lime-soda process and the base-exchange process. Temporary hardness can also be removed by sufficient boiling so as to decompose the bicarbonates of calcium and magnesium with evolution of carbonic acid gas and precipitation of the carbonates of calcium and magnesium. The reactions which take

place under such conditions may be represented by the following equations :

$$Ca\,(HCO_3)_2 = CaCO_3 + H_2O + CO_2$$

$$Mg\,(HCO_3)_2 = MgCO_3 + H_2O + CO_2$$

This process is not adopted under practical conditions as it is costly and results in only partial precipitation of magnesium carbonate.

(i) *Lime-soda process.*—In this process the calcium and magnesium salts dissolved in the water are converted into calcium carbonate and magnesium hydroxide (which are only sparingly soluble in water, 0·013 gram of calcium carbonate and 0·01 gram of magnesium hydroxide being soluble per litre of water) which are precipitated and removed by settlement or filtration. Besides the calcium and magnesium salts, a certain amount of colouring and organic matters are also removed from the water by this process.

Temporary hardness.—Temporary hardness caused by calcium bicarbonate is removed by the addition of a sufficient quantity of quicklime, used in the form of milk of lime, to bring about the following reaction :

$$Ca(HCO_3)_2 + CaO + H_2O = 2\,CaCO_3 + 2\,H_2O$$

Removal of temporary hardness caused by magnesium bicarbonate is effected by the addition of a sufficient amount of quicklime to bring about the following reaction :

$$Mg(HCO_3)_2 + CaO + H_2O$$
$$= MgCO_3 + CaCO_3 + 2\,H_2O \quad \ldots \quad (i)$$

Magnesium carbonate is however appreciably soluble in water (0·1 gram of magnesium carbonate being soluble per litre of water). It is therefore converted into the sparingly soluble magnesium hydroxide by adding additional amounts of lime :

$$MgCO_3 + CaO + H_2O = Mg(OH)_2 + CaCO_3 \quad \ldots \quad (ii)$$

From equations (*i*) and (*ii*), we have,

$$Mg(HCO_3)_2 + 2\,CaO + 2\,H_2O$$
$$= Mg(OH)_2 + 2\,CaCO_3 + 2\,H_2O$$

Permanent hardness.—After the removal of temporary hardness, the permanent hardness may be removed in the following manner :—

Permanent hardness due to calcium salts (chloride, sulphate and nitrate) is removed by the

addition of a sufficient quantity of sodium carbonate to form calcium carbonate ; *e.g.*,

$$CaCl_2 + Na_2CO_3 = CaCO_3 + 2\ NaCl$$

Removal of permanent hardness due to magnesium salts (chloride, sulphate and nitrate) is effected by the addition of the requisite quantities of quicklime and sodium carbonate. The lime reacts with the magnesium salts with the formation of the corresponding salts of calcium and magnesium hydroxide ; the sodium carbonate then reacts with the calcium salts resulting in the precipitation of calcium carbonate and the formation of the corresponding salts of sodium, *e.g.*,

$$MgCl_2 + CaO + H_2O = Mg(OH)_2 + CaCl_2$$

$$CaCl_2 + Na_2CO_3 = CaCO_3 + 2\ NaCl$$

$$MgCl_2 + CaO + Na_2CO_3 + H_2O$$
$$= Mg(OH)_2 + CaCO_3 + 2\ NaCl$$

With a view to softening a particular water, it is necessary to determine the nature and amounts of calcium and magnesium salts present in it. The quantities of the precipitating reagents required to convert these salts into calcium carbonate

and magnesium hydroxide are next calculated. The degree of purity of the reagents should be ascertained, and due allowance made for this when estimating the amounts necessary. It must be noted that most natural waters contain a small quantity of free uncombined carbonic acid gas in solution. Allowance should be made for this also in calculating the quantities of lime required for the softening treatment, because free carbonic acid gas will convert a part of the added lime into calcium carbonate in accordance with the following equation :

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$$

After the addition of the requisite quantities of the reagents, sufficient time should be allowed for completion of the reactions and for the sedimentation of the precipitated solids which carry down with them the oxides of iron and manganese and also considerable quantities of organic matter and living organisms. The supernatant clear water is subsequently drawn off, or it may be filtered to remove the precipitates. It is however impossible to completely remove the hardness of water by this process of softening, because small amounts of calcium carbonate and magnesium hydroxide are retained in solution. Lime-softened

water may be supersaturated with the normal carbonates of calcium and magnesium, and filters, cisterns and hot-water systems are liable to become choked with deposits of carbonates. This difficulty can be prevented by adding carbonic acid gas to the water before filtration.

(*ii*) *Base-exchange process.*[1]—In this process the property of base-exchange possessed by certain hydrated aluminosilicates is employed. The base-exchanging materials are known as " zeolites " which naturally occur most commonly in cavities and veins in basic igneous rocks and less frequently in gneiss, granite, etc. In 1906, Dr. Gans of Berlin produced zeolites artificially and named his product " permutit " (from Latin *permutare*, to exchange). The artificial zeolites are sold under trade names such as basex, permutit, etc. They are prepared commercially by fusing appropriate ingredients (such as kaolin, quartz, and sodium carbonate) followed by leaching with

[1] *References* :—(1) ' A Text-book of Mineralogy,' E. S. Dana, p. 547.

(2) ' A Text-book of Inorganic Chemistry,' by J. N. Friend and D. F. Twiss, Vol. VII, Part I.

(3) ' Water Softening: the Base-exchange or Zeolite Process,' A. R. Martin, Water Pollution Research Technical Paper No. 1, Department of Scientific and Industrial Research.

hot water, by mixing solutions of sodium aluminate and sodium silicate usually at a temperature below 20°C. in such a way that the whole mass sets to a gel which is afterwards dried and broken up, or by other methods. When hard water is passed through a layer (2-3 feet deep) of sodium zeolite, the calcium and magnesium compounds present in the water are exchanged by chemically equivalent proportions of the corresponding sodium salts, the original sodium zeolite being converted into a calcium or magnesium zeolite as shown in the following equation:

$$Na_2O,\ Al_2O_3,\ xSiO_2,\ y\ H_2O + CaCl_2$$
$$= CaO,\ Al_2O_3,\ xSiO_2,\ yH_2O + 2NaCl$$

$$Na_2O,\ Al_2O_3,\ xSiO_2,\ yH_2O + MgSO_4$$
$$= MgO,\ Al_2O_3,\ xSiO_2,\ yH_2O + Na_2SO_4$$

In time the sodium zeolite becomes exhausted owing to its conversion into calcium or magnesium zeolite. It is then regenerated by passing through it some 10% solution of common salt when the calcium or magnesium in the zeolite is abstracted and the sodium restored, and the reformed sodium zeolite is ready again for the treatment of more hard water. This method is capable of reducing a hard water to one showing little or no hardness

and it has attained considerable popularity as a convenient method of softening household water supplies. It is however inapplicable to turbid, ferruginous and acid waters. Waters of a high degree of temporary hardness are efficiently and economically softened by employing a preliminary rough lime-soda treatment and then completing the softening by the zeolite.

Elimination of Iron, Lead, etc.

Iron.—In the lime-soda process of water-softening, all but minute traces of dissolved iron compounds are precipitated and removed together with suspended impurities and the solid particles which are deposited from solutions in the softening process. When the water is not to be softened, the usual process is to thoroughly aerate the water. Aeration drives off the carbonic acid gas and introduces oxygen into the water in order to oxidise the soluble ferrous bi-carbonate into the insoluble ferric oxide which can then be removed by sedimentation, or better by filtration. If iron is present in colloidal forms the use of a coagulant (such as aluminium sulphate) followed by a period of settlement and filtration will produce a water free from all traces of iron.

Iron may be eliminated also by means of a manganese zeolite which is prepared by treating a sodium zeolite with a solution of manganese chloride. The manganese zeolite is next treated with a solution of potassium permanganate when highly oxidised manganese compounds are formed throughout its mass. If the ferruginous water is now filtered through a manganese zeolite so treated, the ferrous salts are oxidised, precipitated and removed by the filtering action. When exhausted or reduced, the zeolite is regenerated by treatment with 2-3 per cent. solution of potassium permanganate.[1]

Lead.—For the removal of lead, alum (20 to 30 milligrams per litre) is added first and then sodium sulphide slightly in excess. Lead is precipitated as lead sulphide which is removed by filtration.

Copper.—The copper salt is converted into the insoluble cupric hydroxide by the addition of lime. The insoluble cupric hydroxide is next removed by filtration.

Removal of Colour, Odour and Taste.

The colour will be bleached when the water is exposed to sunlight and air. The colouring

[1] 'Water Purification and Sewage Disposal,' by J. Tillmans and H. S. Taylor, p. 86.

matter may be rendered insoluble by the use of aluminium sulphate or any other coagulant and removed by filtration. The activated carbon also can remove practically every kind of organic colour.

Aeration is nature's method of removing undesirable odours and tastes. The addition of coagulants, slow-sand filtration, ammonia-chlorine treatment or activated carbon has a considerable power of reducing and removing odours and tastes. Objectionable tastes can in certain cases be effectually removed by the addition of minute quantities of potassium permanganate to the water, the dose of potassium permanganate varying with the oxidisability of the particular water.

Destruction of Algal Growths.

Algal growths can be destroyed by the use of chlorine (about 1 part of chlorine per million parts of water) or copper sulphate (2 to 10 pounds per million gallons of water). The excess-lime process also has proved successful in dealing with water containing algae, as the growths are precipitated in the sludge and are then removed from the water. The remedial measures aimed at removing the algal troubles should,

however, be conceived in a rational manner on a study of individual cases. For instance, spirogyra (commonly known as *sheola* in Bengali) is one of the common green algae growing in masses in tanks. The masses of this alga could be easily removed by hand ; the soil from the sides and bottom of the tank should also be removed so as to get rid of algal spores and resistant forms.

Distillation.

Distillation would separate all solids and effect a more complete purification of water than any other method. The elimination of all soluble salts is not, however, usually necessary or desirable in potable waters, but there are instances in which a considerable reduction would be an advantage. This method is very expensive and is only made use of in the last resort (as in the Royal Navy and Mercantile Marine and maritime stations such as Aden) when nothing better than sea water or brackish water is available.

CHAPTER XII

CONCLUSION

Bengal is not a waterless desert. The province is blessed with abundant monsoon rains. There is a network of rivers formed chiefly by the main rivers (the Ganges, the Brahmaputra and the Meghna), their affluents and tributaries and the inter-connecting smaller channels called khals. Rivers form the boundaries of most of the districts and of many of the sub-divisions, and towns and villages sprang up on the banks of rivers and khals. The water from these natural sources is used by the people in their neighbourhood almost universally. In Darjeeling and in parts of Jalpaiguri District, springs are widely used. In many localities there are large natural swamps which serve the neighbouring villages. The natural sources of water have also been supplemented artificially by means of tanks and wells. In fact, the majority of the villages are honeycombed with tanks. Numerous wells are also found in many villages, water

being available at a depth of a few feet only from the surface in the alluvial soils of Bengal. During the past few years, deep tube wells, sunk to a depth of from 60 to 200, or even 300 to 500 feet, have been found successful in most of the plains districts. In a country like ours it is therefore difficult to realise that in some parts of the world engineering works of immense magnitude have been undertaken to secure an adequate supply of suitable water. In Australia, many artesian borings are sunk to depths of over 4,000 feet beneath the surface of the soil to obtain supplies of water. In New York, a suitable supply of water is not available near-by, but the city utilizes the large rainfall on the Catskill mountains; the water is first collected in reservoirs on the Catskill mountains and then transported through aqueducts, 92 miles long, at the rate of 600 million gallons per day. In San Francisco, the water is conveyed from a still greater distance, the total length of the aqueduct from the Sierra Nevada mountains to the town being 156 miles. Enormous dams have been constructed in some parts of the world to impound the rainfall or flood water which would ordinarily run off, and the water is subsequently released throughout the dry months of the year through an elaborate network

of channels. The Hoover Dam in Southern California, designed to impound the flood water of the Colorado river is the highest and the artificial lake which it forms is the most capacious of its kind in the world. The Cauvery Dam at Mettur in the Madras Presidency has a storage capacity of over 2,500 million tons of the flood water of the Cauvery, and forms the largest reservoir in India. By the construction of a barrage across a perennial river, the flow of water can be regulated with a view to retaining the water above it at any desired height instead of letting it flow uselessly into the sea. The Lloyd Barrage at Sukkur in Sind across the Indus is the greatest work of its kind yet built; its purpose is to produce a higher level on the up-stream side so as to enable the water to flow easily into the canals (on both sides of the river above the barrage) which are thus given a steady supply of water at a fairly constant level for perennial irrigation ; as a result, a huge tract of sandy wastes in Sind has been converted into a vast crop-producing country.

In Bengal, it may be observed that although for the greater part of the year there is an abundance of water in the rivers and khals, tanks and wells, a serious shortage of potable water occurs

in most villages in the hot-weather months owing to the fact that in many places the wells run dry, the tanks either dry up or contain a small volume of dirty water and a large number of the rivers and khals are more or less moribund and unable to fulfil their old function of supplying good drinking water. In a town, however, the municipality provides the residents with a pure water supply, the maintenance charges in connection with the municipal water supplies being met principally from income obtained by the imposition of water rates (based on the annual valuation of holdings) upon the house-holders who have house-connections; street stand posts are also erected from which poor people, who are unable to afford house-connections, carry away water in their own vessels. In rural areas, the solution of the problem of the scarcity of drinking water is to be found in the conservation and supplementation of the sources of water on the one hand, and the protection of these sources from pollution on the other.

Conservation and Supplementation of the Sources of Water.

The rivers and khals of Bengal are steadily deteriorating, and their conservation is

a costly task. The Government and the District Boards seem called on to work in unison to maintain the integrity of the river system. In recent years attention is being given to the improvement and maintenance of the waterways in Bengal. It is expected that the Waterways Board will do for the waterways of Bengal what the Improvement Trust is doing for Calcutta. Under the Bengal Development Act, the Government also contemplate the resuscitation of water channels which are in progress of decay and the opening of new channels with a view to developing the lands on both sides of the channels by affording irrigational facilities, and the cost of schemes financed by the Government out of loan funds will be met by the imposition of a levy on increased profits which would accrue to the occupiers of lands owing to improvement works undertaken by the State.

Nearly every household possesses a tank or well. This must be properly cleaned and well kept. It is only through the neglect of the owners that the tanks and wells, which were in perfectly good condition at one time, are now out of repair and have consequently fallen into disuse. When there is already a source of water supply, it is more economical to improve and conserve it

rather than to supplement it. The numbers of tanks, wells and tube-wells (the construction of which is proceeding apace in Bengal villages within recent years) are to be increased only when there is not an adequate system of water supply. It often happens that the villager is not well enough off to pay for the cleaning and sinking of wells, excavation and re-excavation of tanks, installation of tube-wells, etc., and in consequence cannot satisfy his wants by his own efforts. Fortunately, there is a tradition of corporate action for mutual benefit to which to appeal. The villager instead of being individualistic in character may unite with his neighbours and share with them the expenses and advantages of economically obtaining good drinking water. There is, in fact, ample room for the establishment of co-operative societies for the purpose of providing a good supply of drinking water, as for improving other kinds of amenities of village life.

The Government as well as the District Boards spend annually a portion of their income for the provision of potable water supplies in rural areas, and every year tanks are cleaned and excavated or wells constructed in each district on main public thoroughfares or at common public resorts (such as a hāt or bazar) for the benefit of the general

population, or in sparsely populated villages where the people are so poor as not to be able to provide water supplies at their own costs. The water supply of a centre, from which water-borne epidemic diseases (*e.g.*, cholera) are commonly diffused throughout a district, is also a matter of general concern and a District Board might reasonably check the spread of the disease by providing a suitable source of water supply. In Bengal, excluding Calcutta and Chittagong Hill Tracts, there are 26 districts containing 86,242 villages. The number of villages in each district averages 3,317 with an average population of about 540 persons in each. If each village is to be provided with at least one tank or one tube-well, although that can at most serve a very limited population, the capital and maintenance cost involved will be an enormous one. It is thus obviously impossible either for the Government or for the District Boards to attempt directly to provide each village with a sufficient supply of pure water. The portion of the Government or District Board's income which is earmarked for rural water supply, should be spent in the form of grants-in-aid to Union Boards or voluntary associations to supplement the fund which they raise themselves so that the Government or the District Board fund may not be saddled with the cost of

maintenance which will be met by those who are benefited. By mobilizing local resources and encouraging local efforts with pecuniary help, the District Board should be able to bring into being a large number of sources of good drinking water every year in the villages of Bengal.

Protection of the Sources of Water from Pollution.

With the exception of deep tube-wells, practically every source of water in the villages is liable to pollution with organic matter, either of vegetable or animal origin. Ordinarily the people take water from a near source provided it is not filthy-looking or excessively brackish instead of going some distance for better supplies. The greatest hazard to man is found in a water polluted with human faeces; there is comparatively little danger from water containing the excrements of other animals, and there is still less danger in water contaminated with organic matter of plant origin. In rural areas, excremental fouling of land and water is widespread. A water supply may be polluted with human faeces which may not be accompanied by pathogenic microbes: nevertheless, human faecal pollution of drinking water is most offensive to the senses and is objectionable on other grounds. In certain diseases, such as cholera, typhoid fever, etc.,

the specific organisms are contained in the dejecta of the sick or carrier persons. When a water supply is polluted with the evacuations of a person who is suffering from, say, cholera, or is a cholera-carrier, myriads of cholera germs mingle with it, and the disease is contracted by the ingestion of cholera organisms with water. In this way a single case of illness, although of the slightest degree and perhaps quite unsuspected in its neighbourhood, might spread disease and death broadcast through infecting the water supply. This knowledge should impress most strongly upon the villagers the necessity of protecting the source of water supply and the catchment area from pollution and to promptly and efficiently remove and safely dispose of all excreta. In fact, the most important factor in the prevention of pollution is education. With enlightenment of the public as to the effects of the pollution of the water supply, there comes a corporate and irresistible appreciation of the need for conserving its purity.

The local authorities possess the power to prevent the fouling of public water supplies. Under Section 90 of the Bengal Local Self-Government Act, a District Board may set apart convenient tanks, parts of rivers, streams or channels situated within the district for the supply of water

for drinking and culinary purposes, and such tanks, parts of rivers, streams or channels, shall be held to be public springs or reservoirs. The Sanitary Inspector appointed by a District Board for each Police Station renders every assistance to ensure the purity of the water supply of the area under his jurisdiction, especially if it is derived from public wells, tube-wells or reserved tanks. Under Section 277 of the Indian Penal Code, the offence of voluntarily corrupting or fouling the water of any public spring or reservoir is punishable with imprisonment extending to three months or with fine extending to five hundred rupees or with both. A Union Board also, under Section 30, clause 2, of the Bengal Village Self-Government Act, may set apart, for the supply to the public of water for drinking or culinary purposes, any tank, well, stream or watercourse and prohibit the pollution of these selected sources of water. Any person disregarding this prohibition is liable to be punished with fine which may extend to twenty-five rupees.

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